The Loci of Age of Acquisition and Word Frequency Effects: Evidence from Contemporary Experimental Paradigms and Eye-Tracking

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Abstract

Previous research has demonstrated that earlier acquired and frequently occurring words and concepts are processed significantly faster and more accurately than their later acquired and infrequently occurring counterparts. These effects have been observed across samples, languages, stimuli sets and experimental paradigms; suggesting that the phenomena are valid and reliable. However, a number of methodological limitations are evident in the literature and these issues have hindered attempts to identify the nature and loci of these effects. These limitations were subsequently addressed in this thesis. This enabled the researcher to investigate the effects of age-of-acquisition (AoA) and word frequency during perceptual processing, semantic processing, indirect lexical access, direct lexical access, lexical retrieval and articulation. The programme of research outlined in Chapter 2 consisted of a systematic series of laboratory experiments which each assessed different aspects of cognitive processing. Standardised, semi-factorial stimuli sets were also designed and implemented throughout this programme of research to improve validity. Furthermore, methodological and analytical elements were controlled across the experimental paradigms to ensure reliability and facilitate the comparison of AoA effects across levels of processing. Chapters 3 – 8 report six studies consisting of twelve semi-factorial experiments in which the effects of AoA and word frequency were investigated during perceptual identification, picture-category verification/falsification, picture-name verification/falsification, immediate picture naming task, immediate word reading task and delayed picture naming. These experiments revealed that AoA exerted significant, strong and consistent effects on processing speed across all of the experimental paradigms reported in this thesis when

word frequency, imageability, concreteness, familiarity, visual complexity, orthographic neighbourhood density, picture-name agreement and word length were controlled. However, word frequency did not exert a consistent, significant effect when AoA, imageability, concreteness, familiarity, visual complexity, orthographic neighbourhood density, picture-name agreement and word length were controlled. Therefore, AoA effects were independent of word frequency effects. Chapter 9 reports a comparison of the AoA effects which were observed across these experimental paradigms. This chapter indicates that while AoA influenced all levels of processing, the effects were strongest during tasks which required indirect lexical access and arbitrary mapping between levels of representation. These findings lend considerable support to the multi-loci perspective and dispute both the Phonological Completeness Hypothesis (PCH) and the Semantic Hypothesis (SH). Indeed, AoA is a prominent factor which plays a pivotal role in determining processing speed throughout cognitive system rather than solely during one level of processing. Based on the evidence reported in this thesis, the researcher subsequently argues in Chapter 10 that there is at least one, strong locus of AoA effects which occurs during semantic-lexical encoding and at least one weaker locus which occurs during perceptual-semantic encoding.

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Dedications

I would firstly like to dedicate this work to my father, Charles (Charlie) Preece, who was there for the start of the journey but tragically passed away in November 2009. I would also like to dedicate this work to my grandmother, Evelyn Nester Jones, who passed away in May 2014. Thank you for always watching over me.

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Chapter 1: Literature Review

1.1 Chapter Overview

Chapter 1 provides an overview of the theoretical bases for investigating the effects of age-of-acquisition (AoA hereafter) and word frequency. AoA refers to the average age at which words and concepts are usually acquired in a typically developing sample (Gilhooly & Gilhooly, 1980; Morrison, Hirsh, Chappell, & Ellis, 2002; van Loon-Vervoorn, 1985, 1989). Word frequency can be defined in several ways but for the purposes of this thesis and unless otherwise stated, word frequency has been operationalised as the number of times a specific word occurs in written texts within a sample of one million words within the CELEX database (Baayen, Piepenbrock, & van Rijn, 1995). In this chapter, it is argued that there are two broad theoretical approaches for interpreting these effects. The first theoretical approach consists of localist perspectives in which processing is believed to occur at a specific stage of the cognitive process. The second broad theoretical approach consists of multi-loci perspectives in which processing is believed to occur across and between multiple stages of the cognitive process. However, both of these approaches have generated considerable research and debate concerning the validity of previous research designs, measures and stimuli. For example, according to localist theories, the effects of AoA and word frequency occur during a specific stage of the cognitive process, such as during perception, the processing of meaning or during access and retrieval of items in memory. Proponents of the Phonological Completeness Hypothesis (PCH) argue that the effects arise during lexical access and retrieval such as during tasks requiring a verbal response (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Garlock, Walley, & Metsala, 2001; Moore, Smith-Spark, & Valentine, 2004). In contrast, proponents of the Semantic Hypothesis (SH) argue that the effects arise when stimuli must be processed for their meaning; such as during tasks requiring categorisation[1] or category verification[2] (e.g. Brysbaert, Van Wijnendaele, & De Deyne, 2000; Ghyselinck, Custers, & Brysbaert, 2004; Ghyselinck, Lewis, & Brysbaert, 2004; Gilhooly & Gilhooly, 1980; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989). Both of these approaches have received empirical support and are consistent with the use of stand-alone experiments which assess specific aspects of cognitive processing. However, this chapter will demonstrate that neither the PCH nor the SH can account for the multitude of varying AoA and word frequency effects which are evident in the literature.

It is argued throughout this thesis that the second approach to interpreting AoA and word frequency effects offers the most parsimonious explanation. Indeed, proponents of the multi-loci perspective argue that there are several, potential widely distributed, loci of AoA and word frequency effects (Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Hirsh, Morrison, Gaset, & Carnicer, 2003; Izura et al., 2011; Lake & Cottrell, 2005; Morrison, Hirsh, Chappell, & Ellis, 2002). For example, according to this perspective, earlier acquired items possess stronger neural connections and lower thresholds for activation than later acquired items. Therefore, this places loci in the distributed connections between levels of processing rather than at a specific and isolated stage. This approach is also consistent with the idea that while AoA and word frequency effects often co-occur, they are independent and as such can be differentiated

[1] Categorisation tasks typically ask participants to sort a collection of items into specified categories.
[2] Participants are presented with a critical item and a category. They then identify if the critical item belongs in the category.

using carefully controlled, systematic and factorial[3] or semi-factorial[4] methodological designs (Brysbaert & Ghyselinck, 2006; Lewis, 2006). However, it is argued in this thesis that further research is required to assess the validity and reliability of this approach. Chapter 1 identifies that studies have often used a wide variety of different stimuli sets, measures, experimental techniques and analyses. This prevents accurate comparisons of the effects observed across specific studies, experimental paradigms, materials and stages of processing. For example, it is not possible to compare and contrast effects which were produced using different stimuli sets, incomparable experimental procedures, different measures or statistical approaches which are prone to the influence of confounding variables. Consequently, the researcher designed, implemented and evaluated a systematic programme of research which utilised tightly controlled semi-factorial stimuli sets, comparable methodologies across a series of experimental paradigms and a consistent approach to analyses.

1.2 The Theoretical Basis for AoA and Word Frequency Effects

It is well documented that words and concepts which are acquired earlier in life and those which occur more frequently within the environment tend to be processed significantly faster and more accurately than those which are learnt later in life or occur less frequently in the environment (Bonin, Barry, Méot, & Chalard, 2004; Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Juhasz, 2005). Furthermore, earlier

[3] A factorial design refers to when one stimuli set which is split into four or more categories (e.g. early acquired and low frequency items, early acquired and high frequency items, late acquired and low frequency items and late acquired and high frequency items).

[4] A semi-factorial design refers to when one stimuli set manipulates AoA while controlling for the effects of word frequency while another stimuli set manipulates word frequency while controlling for the effects of AoA.

acquired and frequently occurring words and concepts are also more resilient to forgetting, interference and cortical damage than later acquired and infrequently occurring items (Anderson, 2008; Bell, Davies, Hermann & Walters, 2000; Catling & Johnston, 2006b; Cuetos et al., 2002, Cuetos, González-Nosti & Martínez, 2005; Cuetos, Herrera & Ellis, 2010; Ellis, 2006; Ellis, 2012; Gale, Forbes-McKay, Ellis, Shanks, & Venneri, 2005; Irvine, Laws & Ferrissey, 2009). This suggests that understanding the nature and scope of AoA effects is of fundamental importance when studying both normal and impaired cognition.

Indeed, AoA effects have been observed across a range of experimental paradigms using pictorial stimuli including object categorisation (Catling & Johnston, 2006c; Johnston & Barry, 2005), face recognition (Bonin, Perret, Méot, Ferrand, & Mermillod, 2008; Lake & Cottrell, 2005; Richards & Ellis, 2008; Smith-Spark & Moore, 2009), picture-name verification (Catling & Johnston, 2006a; Dent, Johnston, & Humphreys, 2008) and picture naming (Bonin, Méot, Mermillod, Ferrand, & Barry, 2009; Catling, Dent, Preece, & Johnston, 2013; Kittredge et al., 2008; Navarette, Scaltritti, Mulatti & Peressotti, 2013; Raman, 2011). AoA effects have also been observed in a variety of tasks using textual stimuli such as during word and sentence reading (Davies, Barbón & Cuetos, 2013; Izura et al., 2011; Juhasz & Rayner, 2006; Raman, 2011), word recognition (Cortese & Schock, 2013), lexical decision (De Deyne & Storms, 2007; Gerhand & Barry, 1999), word associate tasks (Gullick & Juhasz, 2008) and bilingual translation judgements (Bowers & Kennison, 2011; Canseco-Gonzalez, Brehm, Brick, Brown-Schmidt, Fischer, & Wagner, 2010). It is notable that consistent AoA effects have been observed using both subjective measures based on adult estimates of when words are acquired and objective measures based on the prevalence of items within collections of texts or the age at which 75% of children learn the item (e.g. Brysbaert & Cortese, 2011; Brysbaert & Ghyselinck, 2006; Brysbaert & New, 2009; Johnston & Barry, 2006; Juhasz & Rayner, 2003, 2006). There is also evidence that these AoA measures are highly correlated; suggesting that they are valid and reliable indicators of a legitimate psycholinguistic property which is of theoretical and practical importance (Morrison, Chappell & Ellis, 1997). Indeed, when this information is interpreted in context, all of these studies imply that AoA has an important role in the encoding, storage and retrieval of information from both short-term and long-term memory (Anderson, 2008; Cortese, Khanna, & Hacker, 2010; Ellis, Holmes, & Wright, 2010; Cuetos, Herrera, & Ellis, 2010).

However, there is also an abundance of literature regarding the confounding relationships between AoA and other influential psycholinguistic properties. These relationships can confound results if not adequately controlled during the research process and this is particularly salient in the case of the relationship between AoA and word frequency (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Several factors may contribute towards determining which words are learnt earlier in life but it is notable that earlier acquired words do tend to occur more frequently within the language (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). This means that effects which were previously attributed to AoA may in fact be explained by word frequency if this measure was not adequately controlled. Alternatively, despite high intercorrelations, AoA effects retain statistical significance after other influential factors are controlled (Brysbaert & Ghyselinck, 2006; Cortese & Khanna, 2007). This includes word frequency[5], subjective concreteness[6], orthographic neighbourhood size[7], initial phoneme

[5] Measures include normative data from the Celex database (Baayen, Piepenbrock, & van Rijn, 1995), Kučera and Francis (1967) estimates and subcategories of spoken frequency and written frequency.

length[8], subjective imageability[9], subjective familiarity[10], subjective name agreement[11], word length[12] and iconicity[13] and socio-economic status (SES)[14] (Archila-Suerte, Zevin & Hernandez, 2015; Auer & Bernstein, 2008; Catling & Johnston, 2009; Chalard, Bonin, Méot, Boyer, & Fayol, 2003; Cortese & Khanna, 2007; Cuetos, Alvarez, Gonzalez-Nosti, Méot, & Bonin, 2006; Morrison, Hirsh, & Duggan, 2003; Perry, Perlman & Lupyan, 2015; Reilly, Chrysikou & Ramey, 2007). Furthermore, AoA effects are observed in large scale statistical analyses of data derived from a variety of experimental paradigms (Brysbaert & Cortese, 2011; Brysbaert & New, 2009; Cortese & Khanna, 2007). This suggests that AoA measures possess a significant degree of validity and reliability and are not reducible to word frequency or other psycholinguistic variables (Johnston & Barry, 2006). It also implies that AoA is a discrete measure which is of psychological importance when attempting to understand how information is stored and accessed in the cognitive system. Based on this evidence it can be concluded that AoA and word frequency exert pervasive, occasionally co-occurring but also independent influences across levels of processing, behavioural measures, stimuli types, participant samples and various languages. Indeed, in a comprehensive review, Brysbaert and Ghyselinck (2006) identified that AoA effects can be either independent

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[6] The extent to which a word carries a concrete meaning as opposed to an abstract meaning. This is typically based on adult estimates on a Likert scale.

[7] The number of words which can be formed by substituting a single letters in a word (Coltheart et al., 1977).

[8] A ‘phoneme’ is the smallest unit of a language that creates differences in meaning between two words.

[9] How easy it is to picture the corresponding object or concept when presented with the label. This is typically recorded on a Likert scale.

[10] Normative data based on adult estimates of how familiar they are with a word. This is typically recorded on a Likert scale. For example, the MRC Psycholinguistic Database (Coltheart, 1981) merged the normative data from three previous papers (Gilhooly & Logie, 1980; Paívio, Yuille, & Madigan, 1968; Toglia & Battig, 1978).

[11] The extent to which raters agree with the name of an object which is typically recorded on a Likert scale.

[12] Word length can be based on several measures including number of letters, phonemes and syllables.

[13] The extent to which the present form resembles the abstract meaning (Perry, Perlman & Lupyan, 2015).

[14] Socioeconomic status refers to an individuals’ economic and social position. This measure is derived from income, education and occupation.

of or co-occurring with word frequency effects depending on the nature of the stimuli, task and analyses. Table 1.1 presents several examples of studies which have documented AoA effects which co-occur with word frequency effects while Table 1.2 presents examples of studies which have observed AoA effects which are independent of word frequency effects.

These tables demonstrate what while frequency-independent and frequency-related AoA effects have been observed across a number of tasks, the stimuli, methodologies and analyses employed during these studies varied considerably. This hinders attempts to compare AoA effects across studies and prevents researchers from fully exploring the nature and loci of these effects. Indeed, numerous factors can influence response times, response accuracy and the interaction between AoA and word frequency. These factors include task complexity (Catling & Johnston, 2009; You, Chen, & Dunlap, 2009), sample characteristics (Morrison, Hirsh, & Dugan, 2003), the level of processing required for successful task completion (Catling & Johnston, 2009; Johnston & Barry, 2006) and the characteristics of stimuli (Barry, Johnston, & Wood, 2006; Lambon Ralph & Ehsan, 2007; Law, Wong, Yeung, & Weekes, 2008; Law & Yeung, 2010; Raman, 2006; Shibahara, Zorzi, Hill, Wydell, & Butterworth, 2003). For example, AoA and word frequency effects tend to co-occur in English word reading which relies on lexical processing and relatively transparent orthographical-phonological mapping[15] (Zevin & Seidenberg, 2002). In contrast, this interaction is less prominent in picture naming which utilises indirect lexical access via the visual and semantic properties of the presented objects, rather than orthographical-phonological transparency (Johnston & Barry, 2006; Juhasz, 2005). This is consistent with the review

[15] The correspondence between the spelling of the word and the correct pronunciation.

provided by Brysbaert and Ghyselinck (2006). However, there is still considerable debate concerning the theoretical bases for identifying the loci of these effects, the validity of certain AoA measures and the sensitivity of traditional experimental techniques to detect the full range of AoA effects occurring within complex cognitive systems (Brysbaert & Cortese, 2011; Brysbaert & New, 2009; Catling & Johnston, 2006a, 2006b; Lewis, 2006). The studies presented in this thesis resolved these issues through the development of a systematic programme of research which maintained consistency across stimuli, sampling, methodologies, analyses and interpretation. In order to identify the most appropriate approaches, the theoretical and methodological bases of AoA and word frequency effects were considered in more detail in the following sections.

Previously, the Phonological Completeness Hypothesis (PCH hereafter) and the Semantic Hypothesis (SH hereafter) were the most prominent theories concerning AoA effects. However, there has been a gradual theoretical shift away from localist accounts and towards theories advocating multiple or dispersed loci (Catling & Johnston, 2006a, 2006b; Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Juhasz, 2005). However, each of the theoretical perspectives has produced substantial literature with numerous insights into AoA and word frequency effects. The following sections of Chapter 1 discuss and evaluate these theoretical perspectives and the corresponding empirical evidence. The common limitations of previous studies are also acknowledged before the ways in which these issues can be resolved are identified.

Table 1.1 Studies reporting AoA effects which are related to word frequency

Authors	Task(s)	Critical Stimuli	Display Time	Analyses	Findings
Barry, Morrison, & Ellis (1997)	Normative Task Object Naming	195/260 items from Snodgrass & Vanderwart (1980) selected post-hoc. Controlled for familiarity, name agreement, complexity & imageability	Response triggered	Multiple regression	Frequency effect AoA x Frequency interaction Name agreement effect
Brysbaert & Ghyselinck (2006)	Multi-task investigation; Lexical decision, Categorisation, Word associates Picture-naming Object/non-object decision	Pictures and words from various sources with different characteristics	Various	Correlation of results from each study	Co-occurring AoA & Word Frequency effects in most tasks (equal magnitude) However, not in object naming or word associate tasks
Brysbaert, Lange, & Van Wijnendaele (2000)	Immediate naming Lexical decision Masked priming	Six stimulus lists of 24 four- and five-letter words. Measures for AoA, word frequency & imageability.	770 ms	Multiple regression	AoA effect Frequency effect No imageability effect
Gerhand & Barry (1999)	Lexical decision (5 experiments with varying methodology)	Four factorial stimuli sets consisting of 64 words in total (taken from Gilhooly & Logie, 1980). Matched for concreteness, imageability & word length	Response triggered	ANOVA	AoA effects Frequency effects AoA x Frequency interaction

Table 1.2 Studies reporting AoA effects which are independent of word frequency

Authors	Task(s)	Stimuli	Display Time	Analyses	Findings
Brysbaert & Ghyselinck (2006)	Multi-task investigation components for object naming & word associates	Various. Pictures and words from various sources with various characteristics	Various	Correlation of AoA & word frequency results from each study	AoA effects in object naming & word associate generation
Cortese & Khanna (2007)	Word reading Lexical decision	2,870 single-syllable words from Seidenberg & McClelland (1989).	Response triggered	Hierarchical regression	AoA effect in lexical decision but not word reading Frequency effect in word reading but not lexical decision
Juhasz & Rayner (2006)	Word reading Eye-tracking	72 target words from Coltheart, (1981). Experiment 1: Factorial & controlling concreteness, imageability & familiarity with partial success. Experiment 2: Semi-factorial.	Response triggered	ANOVA (experiment 1) ANCOVA (experiment 2)	AoA effects Frequency effects No AoA x Frequency interaction
Cuetos, Alvarez, Gonzalez-Nosti, Méot & Bonin (2006)	Picture-naming (5 experiments using different measures of AoA and word frequency)	Factorial sets in experiments 1-4 with various measures of AoA, word frequency, familiarity, imageability, complexity, word length & name-agreement. Non-factorial set in experiment 5 including all of the measures experiments 1-4.	Response triggered	ANOVA (Experiments 1-4) Multiple regression (Experiment 5)	AoA effects in all analyses. Frequency effects in by-subject analysis only for experiments 1, 3 & 4. Cumulative frequency & frequency trajectory effects in experiment 5. Inconsistent interaction

1.2.1 Phonological Completeness Hypothesis

Proponents of the PCH argued that cognitive systems possess limited resources for encoding and retrieving word forms from the mental lexicon[16] (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Garlock, Walley, & Metsala, 2001; Moore, Smith-Spark, & Valentine, 2004). As earlier acquired and frequently occurring words would be learnt when resources were still plentiful they would possess optimal status in the mental lexicon as unified representations (Johnston & Barry, 2006; Juhasz & Rayner, 2006). These stimuli would require minimal processing for successful retrieval and production which in turn facilitates rapid and accurate responses. Conversely, the elements of late acquired and infrequent words would be widely distributed throughout the mental lexicon due to occurring when resources were increasingly scarce after the entrenchment of earlier acquired and frequently occurring items. Widely distributed representations would hinder processing due to requiring more extensive integration prior to successful retrieval. This demonstrates how earlier acquired items may configure the lexical system to their advantage during the fundamental stages of learning according to the PCH (Brown & Watson, 1987).

In support of this theory, early studies tended to observe AoA effects during tasks that require lexical access and articulation but not in those dominated by semantic processing (Barry, Hirsh, Johnston, & Williams, 2001; Morrison, Ellis, & Quinlan, 1992; Johnston & Barry, 2006). These findings suggested that AoA exerts its influence predominantly during the final stages of lexical processing rather than during the earlier stages of identification, recognition, semantic processing and the initial stages of lexicalisation consistent with the principles of the PCH. Neuroimaging studies have also

[16] The mental lexicon is a hypothetical catalogue of words which are present in a language.

indicated increased cortical activity in areas associated with focused auditory-phonological processing[17] and articulatory-motor planning[18] when participants processed late acquired items compared to when they processed earlier acquired items during both covert word reading and overt picture naming (Cuetos, Barbón, Urrutia, & Domínguez, 2009; Ellis, 2012; Ellis, Burani, Izura, Bromiley, & Venneri, 2006; Hernandez & Fiebach, 2006; Hernandez, Hofmann, & Kotz, 2007; Weekes, Chan, & Tan, 2008). This supports the PCH prediction that late acquired items may require more effortful lexical processing than earlier acquired items. However, cortical regions are not exclusive to any one form of processing and are highly interconnected with other regions of the brain (Cohen, Johnston & Plunkett, 2002). Indeed, a change observed in one area of the brain may not have originated in or be confined to that region.

Several studies which investigated the neural basis of AoA also detected significant correspondence between the processing of earlier and later acquired items and activation of regions in the anterior temporal lobes (Cuetos, Herrera & Ellis, 2010; Ellis et al., 2006; Woolams, Lambon Ralph, Plaut, & Patterson, 2008; Venneri, McGeown, Hietanen, Guerrini, Ellis, & Shanks, 2008). These areas are more frequently associated with semantic memory than lexical processing. This suggests that semantic properties can also influence the emergence of AoA effects, in addition to lexical properties. For example, patients with neurological conditions which hinder processing, such as in the case of semantic dementia, Alzheimer's disease or aphasia, still demonstrate a tendency to process earlier acquired items significantly more accurately than later acquired items. Such patients tend to also demonstrate notable deficits and

[17] For example, this occurs when participants are asked to repeat words which the experimenter reads.
[18] Articulatory-motor planning refers to the cognitive processes which occur when planning the movement of the verbal apparatus (e.g. lips, tongue, teeth, vocal cords and larynx). While this may appear to be automatic, it is a very complex process which must be learnt.

damage in regions associated with both semantic and lexical processing, preventing the identification of a singular locus for these effects (Ellis, 2012; Cuetos, Aguado, Izura, & Ellis, 2002; Silveri, Cappa, Mariotti, & Puopolo, 2002). This demonstrates that the PCH cannot adequately explain all AoA effects due to co-occurring links to cortical regions associated with semantic processing.

Similar findings have been observed in neurologically healthy samples (e.g. Ellis, 2012; Ellis, Burani, Izura, Bromiley, & Venneri, 2006; Fiebach, Friederici, Müller, von Cramon, & Hernandez, 2003). For example, Ellis et al. (2006) observed increased patterns of activation in the cortical regions associated with semantic processing when participants named earlier acquired items compared to the level of activation observed when they named later acquired items, suggesting that semantic processing plays a significant role in the emergence of AoA effects. Notably, the PCH is not equipped to adequately explain these differences due to failing to consider the possibility that AoA effects occur during earlier stages of processing. These findings may arise due to several different mechanisms, processes or structures, suggesting that conclusive evidence regarding the origins of AoA effects cannot be drawn based solely on the PCH. Therefore, contrary to the assumptions of the PCH, AoA effects observed in lexical tasks may not arise solely due to phonological processing but could have originated during earlier stages of processing or even accumulate across the cognitive system (Catling & Johnston, 2006a, 2006b, 2009; Colins & Loftus, 1975; Gilhooly & Gilhooly, 1980; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989).

The PCH is also limited by a number of other issues which can undermine the validity of this account. For example, there is a considerable lack of consensus concerning the number of subsystems involved in lexicalisation, the number and nature of routes to articulation and the general organisation of the mental lexicon (Barry, Johnston, & Wood, 2006; Coltheart, Laxon, & Keating, 1988; Juhasz, 2005; Lewis, 2006; Morrison, Hirsh, & Duggan, 2003; Raman, 2006; Shibahara, Zorzi, Hill, Wydell, & Butterworth, 2003). These issues subsequently limit the scope of the PCH and hinder researchers' attempts to establish direct correspondence between the principles of the PCH, the processing stages accessed by these research techniques and the loci of AoA effects (Catling & Johnston 2006a, 2006b; Johnston & Barry, 2006; Lewis, 2006; Juhasz, 2005). Indeed, as the structures and processes involved in lexicalisation are contested, the distinction between stages is not conceptually explicit making the transition between levels of processing difficult to map and test empirically (Johnston & Barry, 2006; Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Studies within the PCH sphere are often outdated and were based on unreliable stimuli sets or unrepresentative samples (Lewis, 2006). They also tended to employ multiple regression while failing to consider numerous other influential psycholinguistic variables (Lewis, 2006; Morrison, Chappell & Ellis, 1997; Zevin & Seidenberg, 2002, 2004). Such discrepancies reduce the reliability and validity of some of the earlier studies and also hinder the ability of researchers to generalise results to other tasks, participant samples and stimuli sets (Johnston & Barry, 2006; Juhasz, 2005; Lewis, 2006; Zevin & Seidenberg, 2002, 2004).

In addition to these general issues, several studies have also highlighted practical inconsistencies with the PCH. For example, participants perform equally well when segmenting early and late acquired words, suggesting that these stimuli share similar degrees of lexical integration rather than that they are differentiated by the quality of phonological representations (Monaghan & Ellis, 2002; Zevin & Seidenberg, 2002). While AoA effects are pronounced during immediate naming, they dissipate after response delays but are only marginally reduced when researchers use methodologies which suppress lexicalisation and articulation (Catling & Johnston, 2005; Johnston & Barry, 2007; Juhasz, 2005; Holmes, Fitch & Ellis, 2006). This is counterintuitive to loci at the lexical retrieval and articulation stages of processing. However, while AoA effects are observed in tasks which do not *require* articulation, this cannot be used as conclusive evidence against a lexical locus. Indeed, participants may still intentionally or unintentionally retrieve elements of the linguistic form during the identification of a stimulus (Brysbaert, Lange, & Van Wijnendaele, 2000; De Deyne & Storms, 2007; Johnston & Barry, 2005, 2006; Holmes, Fitch & Ellis, 2006; Menenti & Burani, 2007; Navarrete & Costa, 2005; Rayner, Chace, Slattery & Ashby, 2006; Yee & Sedivy, 2006).

Lewis (2006) and Stadthagen-Gonzalez et al. (2009) argued that it is not possible to isolate stages of processing using conventional research techniques due to a lack of time-sensitive measures and the issues associated with establishing clear conceptual boundaries between processing stages. However, some degree of separation may be possible through the use of more time-sensitive indicators than manual and verbal response times; such as through the incorporation of electrophysiological measures and eye-movements (Brysbaert & Cortese, 2011; Ellis & Lambon Ralph, 2000). Indeed, when studies have used time-sensitive measures and have attempted to assess perceptual processing, AoA does appear to exert a small but statistically significant influence which the PCH does not predict (Catling, Dent & Williamson, 2008; Catling & Johnston, 2009; Chen, Dent, You, & Wu, 2009; Dent, Catling & Johnston, 2007; Juhasz & Rayner, 2006). This could not have been assessed without the use of time-sensitive measures. For example, reaction times from manual responses may be confounded by the delay between thought and action while more direct time-sensitive measures are not so easily distorted. Comparing effect sizes based on these measures across a variety of tasks could consequently provide significant insights into the loci and time course of AoA and word frequency effects (Chalard & Bonin, 2006; Juhasz, 2005; Juhasz & Rayner, 2003, 2006; Meyer, Roelofs & Levelt, 2003; Meyer, Sleiderink & Levelt, 1998; Rayner, 1998; Rayner & Juhasz, 2004; Roelofs, 2007; Yee & Sedivy, 2006). For example, experimental paradigms can be adapted to gradually increase processing demands, experimental control and the levels of processing required by varying the response criterion and controlling extraneous influences while obtaining more direct moment-to-moment measures (e.g. Catling & Johnston, 2009; Izura et al., 2011; Juhasz, 2005; Rayner & Juhasz, 2004). Therefore, while phonology may mediate lexical cognition to some extent, perceptual and semantic processing also appear to influence the physiological and behavioural correlates associated with AoA (Juhasz, 2005; Holmes, Fitch & Ellis, 2006; Morrison & Ellis, 2000). Drawing on these findings, the locus of AoA effects could be phonological, semantic or perceptual in nature and experimental adaptations would be required to strategically explore this distinction and establish the validity of the phonological completeness hypothesis.

1.2.2 The Semantic Hypothesis

The SH is also a localist perspective but proponents of this theory argue that AoA influences the organisation of hierarchical semantic networks rather than the organisation and strength of the mental lexicon (Brysbaert, Van Wijnendaele, & De Deyne, 2000; Ghyselinck, Custers, & Brysbaert, 2004; Ghyselinck, Lewis, & Brysbaert, 2004; Gilhooly & Gilhooly, 1980; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989). Therefore, the SH presents an alternative level of analysis to that presented by the PCH. According to the SH, earlier acquired and frequently occurring words can be envisioned as the foundation of conceptual networks (Dent, Catling & Johnston, 2007; Ellis, 2012; Izura et al., 2011; Steyvers & Tenenbaum, 2005). These earlier acquired words and concepts would be characterised by a highly interconnected system of conceptual nodes which are easily retrieved via the automatic spreading activation of related concepts, lower activation thresholds of correct concepts and greater resilience to the influence of competing concepts. For example, the higher order concept ‘fruit’ cues the spreading activation of the network to associated concepts like ‘apple’ but also triggers related items and competitors from neighbouring categories such as ‘vegetables’. The connection between the initial cue, its associated nodes and the correct concept would be well established for early acquired and frequently occurring items due to these factors, resulting in faster and more accurate processing (Davies, Barbón & Cuetos, 2013; Gilhooly & Gilhooly, 1980; Steyvers & Tenenbaum, 2005; Urooj et al., 2014). Conversely, later acquired and infrequent words would subsequently be defined in terms of these already established conceptual networks. This would result in increasingly sparse connections for new items with higher activation thresholds and inherent processing disadvantages (Brysbaert, Van Wijnendaele, & De Deyne, 2000). Figure 1.1 presents an example of a simple semantic network which illustrates how the activation of one concept can result in spreading activation across the semantic network and stimulation of other related concepts. For example, the overarching concept of ‘Animal’ contains several subcategories or types. These subcategories can then be further reduced to specific characteristics.

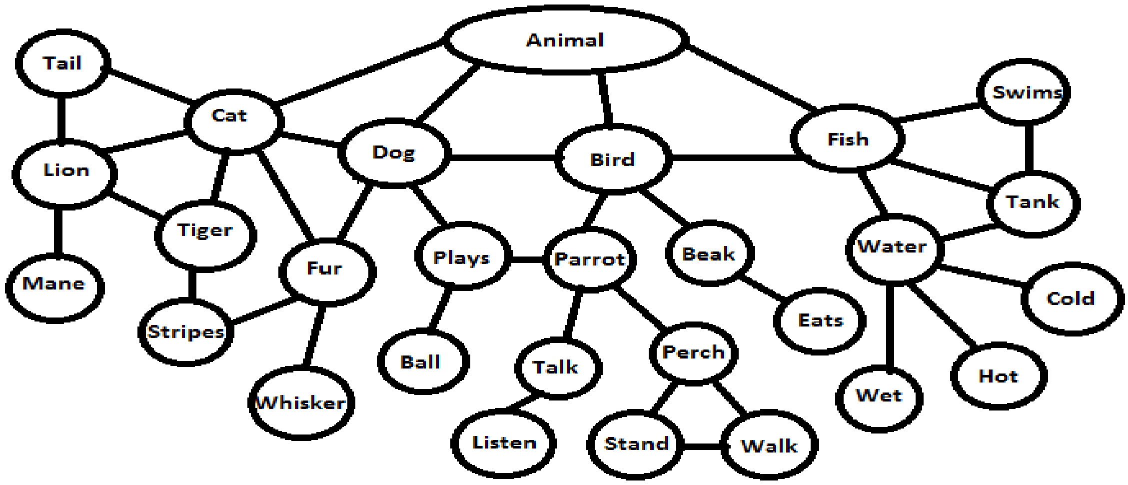

Figure 1.1 Example of a simple semantic network

It is significant that the SH still reduces AoA effects to an isolated level of processing; although this review has identified that both semantic and lexical processing contribute towards AoA effects. However, in addition to the previously discussed AoA effects in semantic tasks such as word association tasks and picture categorisation, neuropsychological and experimental research indicates that earlier acquired words and semantic knowledge are more resilient to damage and interference than the later acquired lexical counterparts (Catling & Johnston, 2009; Chen, Zhou, Dunlap, & Perfetti, 2007; Izura et al., 2011, Johnston & Barry, 2005, Morrison & Gibbons, 2006). For example, the recent study by Catling, Dent, Johnston and Balding (2010) indicated that pictured objects with names which are acquired earlier in life and pictures objects with names which occur frequently within the environment were more resilient to interference from unrelated superimposed words than pictured objects with later acquired or infrequently occurring names. Such findings imply greater interconnectivity between these early acquired concepts at a semantic level rather than during the later stages of lexical access, retrieval and articulation. Therefore, in this thesis several experimental paradigms which assess elements of semantic processing are reported.

Urooj et al. (2014) recently investigated the effects of AoA on cortical activation during covert object naming[19] using Magnetoencephalography (MEG). Urooj et al. (2014) argued that AoA did not influence visual processing but that earlier acquired items gained their advantage during top-down re-activation of the occipital cortex by semantic representations. This demonstrates how semantic nodes may interact with other nodes within the cognitive system. However, it must be noted that these findings do not exclusively support a semantic locus because these effects may be rooted in the connection between perceptual/structural and semantic representations rather than being localised at one specific stage of processing (Bakhtiar & Weekes, 2014; Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2010).

The SH can also explain the residual effects of AoA in clinical groups (Cuetos, Herrera & Ellis, 2010; Holmes, Fitch & Ellis, 2006; Juhasz, 2005; Rodríguez-Ferreiro, Davies, González-Nosti, Barbón, & Cuetos, 2009). For example, using a lexical decision task Cuetos, Herrera and Ellis (2010) observed that AoA effects remained evident within a sample of patients with Alzheimer's disease and that the difference between earlier and later acquired items was more pronounced than that observed in the control group. Silveri, Cappa, Mariotti and Puopolo (2002) also identified that AoA could reliably predict the number of patients with Alzheimer's who could successfully name a variety of items. Furthermore, AoA effects have been observed in expert vocabularies (Stadthagen-Gonzalez, Bowers, & Damian, 2004) while Kittredge, Dell and Schwartz (2007) also observed that later acquired items appeared to exhibit worse

[19] In covert object naming participants name the objects presented silently rather than vocally.

deficits in aphasic picture naming than earlier acquired items. These studies suggest that the integrity of semantic representations appears to play a prominent role in the emergence of AoA effects.

However, these findings are not inconsistent with the perspective that AoA effects will be present in any form of knowledge which is acquired through interleaved learning and that damage to this network produces differential deficits to earlier and later acquired stimuli (Ellis & Lambon-Ralph, 2000). It is also significant that semantic density was not a significant predictor of Kittredge, Dell and Schwartz's (2007) results which is counterintuitive to a semantic locus. It is also notable that the SH does not predict AoA effects at perceptual or lexical stages of processing despite contrary findings (Dent, Catling, & Johnston, 2007; Johnston & Barry, 2006). Furthermore, a potentially strong challenge against the SH was also presented by a series of studies with bilingual groups. These studies demonstrated that while AoA effects are observed in the first and second language, these effects are rarely transferred across languages despite shared semantics (Canseco-Gonzalez, Brehm, Brick, Brown-Schmidt, Fischer & Wagner, 2010; Hirsh, Morrison, Gaset & Carnicer, 2003; Izura & Ellis, 2002, 2004; Juhasz, 2005).

Co-occurring AoA and word frequency effects are less common in other languages than those observed in English. This suggests that the nature of these effects may also vary as a function of orthographic transparency (Ellis & Lambon Ralph, 2000; Zevin & Seidenberg, 2002, 2004). Hence, AoA effects could be language or task specific and are likely to be mediated to some extent by perceptual, semantic and phonological processes rather than being solely routed at one level of processing (Hernandez & Li, 2007; Zevin & Seidenberg, 2002, 2004). For example, AoA effects consistently arise in both Japanese Kanji and Kana (Shibahara, Zorzi, Hill, Wydell, & Butterworth, 2003; Yamazaki & Ellis, 1997). Significantly, Kanji and Kana primarily rely on semantic and phonological processing respectively. Furthermore, AoA effects have been observed during the processing of Chinese characters which rely on orthographic and semantic processing (Chen, Dent, You, & Wu, 2009; Chen, Zhou, Dunlap, & Perfetti, 2007; Law, Wong, Yeung, & Weekes, 2008; Law & Yeung, 2010; Liu, Hao, Shu, Tan, & Weekes, 2008; Liu, Shu, & Li, 2007; Weekes, Chan, & Tan, 2008; Weekes, Shu, Hao, Liu, & Li, 2007; You, Chen, & Dunlap, 2009). These findings lend support to theories that there may be at least two loci of AoA; the first potentially in early orthographic or semantic processing and the second during the later stages of lexical processing (Catling & Johnston, 2009). However, a significant number of studies employing perceptual or semantic tasks have not investigated or controlled AoA, were conducted with unrepresentative samples, failed to incorporate reliable time-sensitive measures, yielded inconclusive results or did not consider the influence of the wide spectrum of related variables (Ischebeck et al., 2004; Lewis, 2006; Meyer, van der Meulen, & Brooks, 2004; Roelofs, 2007; Sirois, Kremin, & Cohen, 2006; Takashima & Yamada, 2010; Underwood, Jebbett, & Roberts, 2004; Weekes, Chan, & Tan, 2008; Weger & Inhoff, 2006; Zevin & Seidenberg, 2002, 2004). These issues significantly limit the conclusions which can be drawn from these studies due to the possibility that results were confounded by these factors.

For example, Holmes and Ellis (2006) observed that AoA effects were not significant during a category verification task after the semantic variable typicality was controlled. This suggests that typicality may have accounted for some of the effects which were previously attributed to AoA in semantically oriented tasks especially when studies failed to control this variable. It is also notable that imageability is also highly interconnected with AoA and other semantic properties but it is rarely adequately controlled in semantic tasks due to this reason. This suggests that imageability could have confounded studies which did not control this variable, although results to date have been inconclusive (Coltheart, Laxon, & Keating, 1988; Cortese & Schock, 2013; Hernández-Muñoz, Izura, & Ellis, 2006; Izura & Ellis, 2002; Nickels & Howard, 1995; Shibahara, Zorzi, Hill, Wydell, & Butterworth, 2003). Therefore, these factors must be controlled to obtain valid and reliable results during AoA research.

Furthermore, studies investigating the effects of AoA during priming suggest that there are multiple loci and that earlier and later acquired items may be differentially affected by priming (Anderson, 2008; Barry, Hirsh, Johnston, & Williams, 2001; Barry, Johnston, & Wood, 2006; Brysbaert & Ghyselinck, 2006; Brysbaert, Lange, & van Wijnendaele, 2000; Catling & Johnston, 2006a, 2006b, 2006c; Lewis, Chadwick, & Ellis, 2002). While earlier acquired items retain their overall processing advantages in picture naming after pictorial primes (within-domain priming) and lexical primes (between-domain priming), later acquired items demonstrate a more pronounced, longitudinal improvement when compared to participants' initial performance with these stimuli (Barry, Hirsh, Johnston, & Williams, 2001; Barry, Johnston, & Wood, 2006; Lewis, Chadwick, & Ellis, 2002; Moore & Valentine, 1998; Yee & Sedivy, 2006). Hence, while both modes of priming appear to generate significant AoA effects, repeated exposure compensates for some of the processing deficit associated with late acquisition. This cannot be explained by localised accounts (Barry, Hirsh, Johnston, & Williams, 2001; Barry, Johnston, & Wood, 2006; Brysbaert & Ghyselinck, 2006).

An additional limitation with localist accounts is that the majority of theories utilise the principles of serial[20] or cascading[21] processing, which would be counterintuitive to the often rapid and multifaceted nature of human processing observed in more complex tasks (Barry, Hirsh, Johnston, & Williams, 2001; Barry, Johnston, & Wood, 2006; Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Lewis, Chadwick, & Ellis, 2002; Reilly, Chrysikou, & Ramey, 2007). Consequently, theories which adopt a singular locus may not provide an adequate explanation of AoA and word frequency effects which require rapid parallel processing. Conversely, theories adopting multiple dispersed loci appear to be more parsimonious and corroborate with such multifaceted findings.

1.2.3 The Multi-Loci Perspective

The multi-loci perspective was derived from connectionist principles. According to these principles, cognitive processing can be understood in terms of a system of computational neural networks which are analogous to the interconnected system of neurons within the human brain. Such models have been used extensively to successfully model, simulate and explore the micro processes and probable outcomes of human processing (Ellis & Humphries, 1999; Hernandez & Li, 2007). Indeed, they have been particularly useful in exploring language acquisition, development and production (Ellis & Humphries, 1999). The multi-loci perspective can adequately explain a wide range of AoA effects based on the biologically routed[22] principles of multiple dispersed

[20] Information is processed in a sequential order. For example, each letter may be processed in order.
[21] This also refers to when information is processed in a sequential order but there may be a cross over between the processing of each element. For example, in the case of presenting participants with the word ‘however’ they may still be still processing ‘how’ when they begin to process ‘ever’.
[22] Connectionism forms analogues between computer systems and the human brain.

loci and rapid parallel processing[23] within the human brain. By following connectionist principles, the multi-loci perspective requires the use of detailed hypotheses, rigorously controlled stimuli sets and the incorporation of experimental paradigms which assess multiple levels of processing. Such control was often lacking in earlier studies resulting in potentially misleading results and demonstrating that connectionism and the multi-loci perspectives can increase the integrity of AoA research (Hernandez & Li, 2007; Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Proponents of the multi-loci perspective argue that AoA effects are emergent properties of any process in which knowledge is acquired gradually through interleaved learning (Ellis & Lambon Ralph, 2000; Lewis, 2006). This would result in loci which are routed in the strength of connections between levels of representations rather than within specific, localised components of the cognitive system (Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Hirsh, Morrison, Gaset, & Carnicer, 2003; Izura et al., 2011; Lake & Cottrell, 2005; Morrison, Hirsh, Chappell, & Ellis, 2002). Therefore, this perspective can account for the diversity of AoA effects observed across forms of stimuli and experimental paradigms (Ellis, Holmes, & Wright, 2010; Ellis & Lambon Ralph, 2000; Izura & Ellis, 2002, 2004; Lake & Cottrell, 2005; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008).

Figure 1.2 presents an example of a basic neural network from which the multi-loci perspective can be extrapolated and explained. In the case of language, the input units can reflect written text, pictorial stimuli or auditory stimuli. The hidden units would consequently reflect the simultaneous cognitive processes which occur during the recognition, encoding, storage and retrieval of information. For example, a unit/node at

[23] Parallel processing refers to when two or more processes are performed simultaneously e.g. processing visual and auditory information.

this level may reflect attention, perception, memory, semantic processing or lexical processing depending on the nature of the model. The output units would then reflect a number of possible responses or the components of a response. As the diagram demonstrates, the connections are a complex system by which information is transmitted across the network. The strength of these connections is altered by experience whereby repeated exposure or particularly early encounters with respective stimuli strengthen connections while other connections may become weak or inactive if they are activated infrequently. The nodes/units also vary in the level of stimulation required for successful activation. For example, in the case of perception, stimuli may need to be present for a certain amount of time to activate an input unit. It is also notable that a high level of activation of a node/unit at the output level facilitates a response. Therefore, different information stored in short-term and long-term memory would produce different patterns of activation within a neural network.

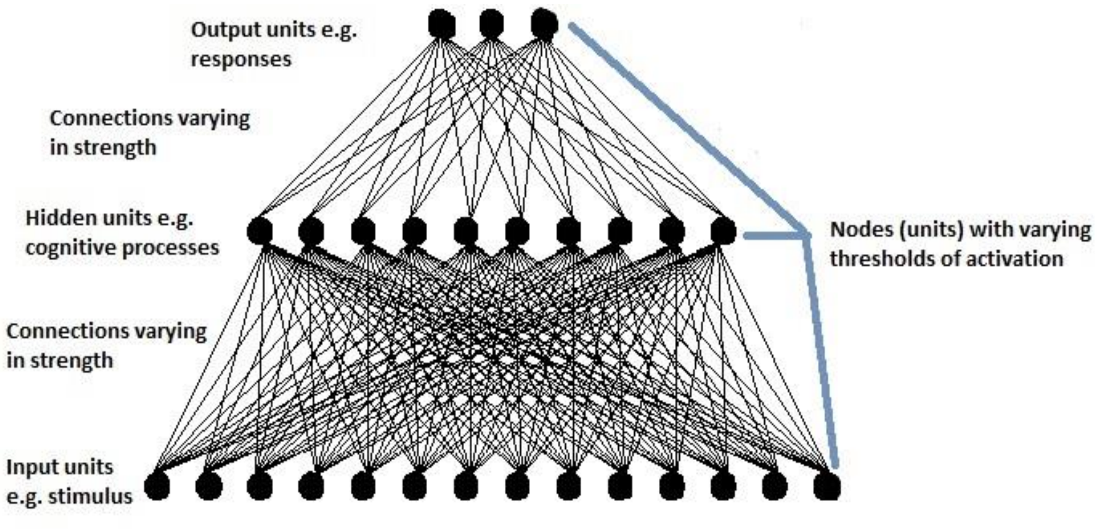

Figure 1.2 Example of a basic connectionist network

Unlike most theories of language, several computational models have already incorporated AoA and word frequency effects as integral elements of linguistic and cognitive processing (Ellis & Humphries, 1999; Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Lewis, Chadwick, & Ellis, 2002). For example, earlier acquired items can elicit longitudinal advantages across a wide spectrum of tasks due to automatically configuring neural networks to recognise their patterns of activation. This is most reliably accomplished at the onset of trainings due to a period of high plasticity[24] when networks are easily altered and would result in lower activation thresholds, stronger weighted connections between nodes, more efficient use of hidden units, less effortful processing, faster responses and greater accuracy (Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Monaghan & Ellis, 2002; Moore, Smith-Spark, & Valentine, 2004).

Indeed, it has been repeatedly observed that stimuli which are introduced into a connectionist model during early training configure the network to their advantage; especially when the training regime is interleaved[25] (Ellis, 2012; Ellis & Lambon Ralph, 2000; Izura et al., 2011; Lambon Ralph & Ehsan, 2006). However, systems of knowledge and the corresponding human capacity to learn new information are limited. Therefore, network plasticity and the availability of processing resources decline with both age and the gradual entrenchment of early acquired items. This prevents significant alteration of the network by later acquired items after the system has been preferentially configured for earlier acquired patterns (Ellis & Lambon Ralph, 2000; Johnston & Braisby, 2000). Therefore, the connectionist principles and the resulting multi-loci

[24] The capacity for the network to change and adapt as new stimuli is introduced. This is one of the processes by which learning occurs through the strengthening of useful connections and the trimming or atrophy of redundant connections.
[25] Interleaved training refers to a pattern whereby items are introduced gradually while learning of previous items continues.

perspective can provide insights into why earlier acquired items display an advantage during human processing.

According to the multi-loci perspective, AoA effects are more pronounced when the mapping between levels of representations is arbitrary (Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Monaghan, Christiansen & Fitneva, 2011; Zevin & Seidenberg, 2002). For example, mapping is arbitrary in irregular orthographies where orthographic properties do not directly translate to phonology and also in the mapping between spelling-meaning such as in picture naming (Bakhtiar & Weekes, 2014; Davies, Barbón & Cuetos, 2013; Ellis & Lambon Ralph, 2000). This would hinder the ability of the network to generalise rules learnt during the acquisition of earlier patterns to those it encounters later in training, consequently facilitating stronger AoA effects. Indeed, in the case of word reading, AoA effects tended to co-occur with word frequency in English while they appear to be more pronounced (and independent of word frequency) in less transparent orthographies. Regular orthographies where the mapping between orthography and phonology is more transparent should elicit fewer AoA effects because the network can generalise the earlier rules thereby reducing the differences between early and late acquired items (Chen, Zhou, Dunlap, & Perfetti, 2007; Brysbaert & Cortese, 2011; Ellis & Lambon Ralph, 2000; Monaghan & Ellis, 2002). Therefore, effects may have been falsely associated with a specific locus rather than arbitrary mapping between levels of processing (Cuetos, Herrera & Ellis, 2010).

Unlike localist accounts of AoA which often fail to directly consider the role of word frequency, proponents of the multi-loci perspective argued that frequency of occurrence mediates connection strengths within neural networks and that the effects of frequency of occurance can subsequently co-occur with the effects of AoA (Alvarez &

Cuetos, 2007; Anderson; 2008; Brysbaert & Cortese, 2011; Brysbaert & Ghyselinck, 2006; Cortese, Khanna & Hacker. 2010; De Deyne & Storms, 2007; Dent, Johnston, & Humphreys, 2008; Ellis, Holmes & Wright, 2010; Kittredge et al., 2008; Lambon Ralph & Ehsan, 2006). This successfully accounts for the high correlation between AoA and word frequency, because frequency may influence the order in which words are acquired. Indeed, later acquired and frequently occurring items may demonstrate fewer processing disadvantages to those elicited by later acquired and infrequently occuring items. However, both of these stimuli sets may still elicit impaired performance when compared to the processing of frequently or infrequently occuring earlier acquired items (Ellis, 2012; Ellis & Lambon Ralph, 2000; Izura et al., 2011).

This can account for the differential effects of frequency observed during within-domain and between-domain priming discussed previously (Barry, Hirsh, Johnston, & Williams, 2001; Barry, Johnston, & Wood, 2006; Lewis, Chadwick, & Ellis, 2002; Moore & Valentine, 1998; Yee & Sedivy, 2006). It is also consistent with Brysbaert and Ghyselinck's (2006) argument that AoA effects can be either related to or independent of the effects of word frequency demonstrating that while AoA and frequency effects tend to co-occur they can also diverge (Brysbaert & Ghyselinck, 2006; Burani, Arduino, & Barca, 2007; Catling & Johnston, 2005; Chen et al., 2007; Cuetos et al., 2009; Havelka & Tomita, 2006; Izura et al. 2011; Pérez, 2007; Weekes et al., 2007). For example, this distinction appears to be reliant upon the nature of the task, mapping between levels of processing and the integrity of the stimuli sets (Brysbaert & Cortese, 2011; Brysbaert & Ghyselinck, 2006; Dewhurst & Barry, 2006; Dewhurst, Hitch, & Barry, 1998; Ellis & Lambon Ralph, 2000; Lewis, 2006). AoA effects would be more pronounced when frequency exerts less of an influence or when learning cannot be generalised between earlier and later acquired patterns. This has been confirmed by Brysbaert and Cortese (2011) who observed that even when more reliable measures of frequency are included in an analysis AoA effects decline but remain prominent. Therefore, the current programme of research employs a semi-factorial design in which the effects of AoA and word frequency are considered separately while controlling for the other variable and a number of other psycholinguistic properties such as familiarity, concreteness, imageability and word length.

There are a number of studies which support the multi-loci perspective that AoA effects should be present in any system of knowledge. For example, Stewart and Ellis (2008) observed that AoA effects were successfully modelled for a categorisation task that employed completely arbitrary checker board configurations. Indeed, earlier acquired patterns were categorised more efficiently than the later acquired patterns despite little or no correspondence between the stimuli and semantic or lexical properties. Furthermore, in a demonstration of how AoA effects can inform real-world issues, AoA effects have also been observed using existing and redundant brand names which were learnt earlier or later in life (Ellis, Holmes, & Wright, 2010). Notably, Izura et al (2011) have recently devised a laboratory analogue of AoA effects which tightly controls extraneous variables using a word training approach where participants learnt a second language over a series of interleaved training sessions. Izura et al (2011) observed age or ‘order’ of acquisition effects on picture naming and lexical decision which persisted for several weeks after training. Catling, Dent, Preece and Johnston (2013) also supported these findings in a study which assessed whether similar effects would be evident during picture naming and visual duration threshold tasks. Catling, Dent, Preece and Johnston (2013) trained participants to recognise symmetrical, three dimensional, computer generated images ('Greebles') with nonsense names. Consistent with a typical learning curve, the training procedure was interleaved so that items were gradually added to the stimuli pool and cumulative frequency was matched across the earlier and later acquired stimuli sets. At test, participants named the earlier acquired items significantly faster than they named the later acquired items. Furthermore, the visual duration thresholds of earlier acquired items were significantly lower than the visual duration thresholds of later acquired items. These studies are consistent with the multi-loci assumptions that longitudinal AoA effects can be obtained using any body of knowledge which is acquired gradually through interleaved exposure and suggests that AoA effects are indeed present throughout cognitive systems (Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008). Indeed, the most consistent AoA effects are obtained using cognitively taxing and multifaceted tasks which require several levels of processing such as in word or picture naming, memory tasks, name or category verification and lexical decision (Barry, Johnston, & Wood, 2006; Catling & Johnston, 2006a, 2006b, 2009; Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Lambon Ralph & Ehsan, 2006; Monaghan & Ellis, 2002). These findings are inconsistent with localised perspectives but can be explained successfully by the multi-loci perspective.

While there are few significant AoA differences observed in comparisons between languages which vary in orthographic transparency, the validity of the orthographic transparency measure and its correspondence to neurological and psychological mapping are not conceptually or methodologically explicit (Brysbaert, 1996; Shibahara, Zorzi, Hill, Wydell, & Butterworth, 2003). This reduces researchers' ability to assess its construct validity and means that it may not necessarily have the conceptual power to undermine the multi-loci perspective. However, Zevin and Seidenberg (2002, 2004) presented an important and influential critique of Ellis and Lambon Ralph's (2000) account. This included the arguments that it draws on unrealistic structures, training and processes, biased measures and inappropriate analyses. For example, they argued that AoA is a behavioural snapshot of a word's acquisition, which is highly intercorrelated with a range of other variables. Consequently, Zevin and Seidenberg (2002, 2004) argued that AoA is not a valid measure and that these effects can be explained by frequency trajectory. For example, words differ in their frequency trajectory across the lifespan, with some items being more common in early life but rarer in later life while the opposite is true for other words. Therefore, this difference in frequency trajectory may explain effects which were previously attributed to AoA (Bonin, Méot, Mermillod, Ferrand, & Barry, 2009; Burani, Arduino & Barca, 2007; Lewis, Gerhand, & Ellis, 2001; Smith, Turner, Brown, & Henry, 2006; Zevin & Seidenberg; 2002, 2004). However, some authors argue that the cumulative frequency and the residency time of words in long term memory can account for the majority of the variance previously attributed to frequency trajectory (Caza & Moscovitch, 2005). Measures of cumulative frequency and the residency time are derived from much larger samples of text than conventional frequency trajectory measures and consequently tend to be more representative of the entire corpus (Brysbaert & Cortese, 2011; Izura et al., 2011; Lewis, Gerhand, & Ellis, 2001). This indicates that there are competing perspectives concerning the validity of AoA and word frequency measures.

However, in contrast to these assertions, the consistently high correlations between subjective and objective measures of AoA, replicable effects across a variety of tasks and corresponding variations in neural activity suggest considerable validity and reliability of AoA (e.g. Bonin, Barry, Méot, & Chalard, 2004; Brysbaert, Van Wijnendaele, & De Deyne, 2000; Hernandez & Fiebach, 2006; Hernandez & Li, 2007; Juhasz & Rayner, 2003, 2006; Morrison, Chappell, Ellis, 1997; Nazir, Decoppet, & Aghababian, 2002). For example, it is often observed that when other variables such as cumulative frequency and frequency trajectory are controlled, AoA remains a significant factor. Conversely, results suggest that the effects of cumulative frequency and frequency trajectory are often inconclusive after AoA has been included in the analysis (Catling, Dent, Preece & Johnston, 2013; Cortese & Khanna, 2007; Cuetos & Barbón, 2006; Ghyselinck, Lewis, & Brysbaert, 2004; Pérez, 2007; Menenti & Burani, 2007). It is also significant that older and younger adults show similar AoA effects despite frequency trajectory predicting a decline with age, implying that AoA and frequency trajectory are not synonymous (Barry, Johnston, & Wood, 2006; Juhasz, 2005; Lewis, Chadwick, & Ellis, 2002:- However, see Bonin, Méot, Mermillod, Ferrand, & Barry, 2009; Smith, Turner, Brown, & Henry, 2006). Therefore, AoA is a valid, reliable and independent measure which is not reducible to the influence of either frequency trajectory or cumulative frequency.

Brysbaert and Cortese (2011) have recently demonstrated that AoA effects may have been exaggerated in earlier studies of word reading and lexical decision due to the use of unreliable frequency measures such as the now out-dated Kučera and Francis (1967) norms (e.g. Brysbaert & New, 2009; Lewis, 2006). They argue that when frequency measures are derived from a larger body of items AoA explains a smaller proportion of the variance in reaction times than previously believed. However, contrary to Zevin and Seidenberg's critique, AoA remained a statistically significant predictor of performance. Cuetos, Barbón, Urrutia and Domínguez (2009) also observed that the event related potentials elicited by words which varied in AoA and word frequency were differentiated by separate time frames. For example, frequency appeared to influence early recognition processes whereas AoA appeared to influence the semantic level or exert its influence during the transition from semantic to phonological processing. This supports arguments that rather than being interchangeable, AoA and frequency elicit significant but independent effects with potentially different loci and time-courses (Barry, Johnston, & Wood, 2006; Bonin, Barry, Méot & Chalard, 2004; Cuetos & Barbón, 2006; Ghyselinck, Lewis, & Brysbaert, 2004; Pérez, 2007). Therefore, there is strong evidence against Zevin and Seidenberg's (2002) critique, although the points raised do require consideration when designing AoA research.

An important point for consideration when discussing Zevin and Seidenberg's (2002) critique is that computational principles and models are only analogous to human processes. They use significantly different materials, structures and processes but are still extremely useful tools for successfully simulating and exploring many forms of cognition, testing theories and generating hypotheses (Broeder & Murre, 2002; Ellis & Humphreys, 1999; Ellis & Lambon Ralph, 2000; Cohen, Johnston, & Plunkett, 2000). This suggests that they are useful tools in cognitive psychology and psycholinguistics. Therefore, despite Zevin and Seidenberg's (2002, 2004) critiques, research and theoretical considerations appear to provide a growing body of support for the multi-loci perspectives. However, as with the earlier perspectives there are methodological limitations with conventional experimental techniques which prevent full evaluation of the practical links between connectionist principles and human processing. For example, further research which utilises time-sensitive measures and multiple, complex experimental paradigms assessing various levels of cognitive processing is required to fully explore and evaluate the multi-loci perspective of AoA.

Indeed, Catling and Johnston (2009) adopted the multi-task investigation and observed that there appears to be at least two distinct and particularly influential AoA effects occurring firstly during structural processing and secondly between semantic and phonological processing. For example, while AoA effects were observed across the cognitive system, the greatest increase in effect size was observed between semantic and phonological levels. This is counterintuitive to localist accounts but is consistent with the multi-loci perspective (Belke, Brysbaert, Meyer, & Ghyselinck, 2005; Brysbaert & Ghyselinck, 2006; Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006). However, further research is required to evaluate this account and explore the nature of and differences between these effects.

1.3 Rationale

Based on the literature reviewed in this chapter, it is clear that while there are a number of theoretical perspectives which may provide partial explanations for AoA and word frequency effects, the multi-loci perspective is the most parsimonious and widely supported account in contemporary AoA literature (Catling, Dent, Preece, & Johnston, 2013; Ellis, Holmes, & Wright, 2010; Izura et al, 2011). Indeed, this approach would account for the AoA effects observed across perceptual, semantic and lexical processing (Catling & Johnston, 2009; Ellis, Holmes, & Wright, 2010). It can also account for why some effects are independent of word frequency while others are interlinked with this measure (Brysbaert & Ghyselinck, 2006; Ellis & Lambon Ralph, 2000). However, several potential areas for development were also identified. This included the need for rigorously controlled experimental adaptation to enable researchers to assess whether there are multiple loci of AoA and word frequency effects. This would also provide insights into where and when these effects occur in the cognitive system. These are the primary objectives of this thesis.

Indeed, it is notable that approaches which only assess lower-order processing or limited aspects of cognition without including time-sensitive measures may not be appropriate for testing multi-loci principles in experimental settings (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Tasks such as object categorisation often rely on basic semantic processing rather than the connections between levels of processing. This implies that loci in these connections are not fully assessed when using this procedure. Indeed, as the multi-loci perspectives place the loci of AoA in the connection strengths between levels of processing, greater accuracy and experimental control are required to identify and differentiate these processes (Ellis & Lambon Ralph, 2000; Zevin & Seidenberg, 2002, 2004). It has been argued throughout this chapter that this could be accomplished using multiple experimental paradigms which are comparable, reliable and valid semi-factorial stimuli sets and time-sensitive measures of moment-to-moment processing (Catling & Johnston, 2009; Juhasz, 2005; Rayner & Juhasz, 2004). Subsequently, for this thesis the researcher designed and implemented a series of standardised laboratory experiments. Each additional experiment gradually increased the processing demands required for successful task completion, while procedural elements remained consistent across experimental paradigms.

1.3.1 Aims and Objectives

This thesis was based on several aims which were implemented to enable the researcher to meet the overall objectives. These objectives were as follows:

- To resolve several of the prominent limitations of previous research including the use of unreliable stimuli sets.
- To expand available methodologies by incorporating time-sensitive measures and reducing procedural inconsistencies across experimental paradigms.
- To identify potential loci of AoA and word frequency effects within the cognitive system.

The first aim was to design two standardised, comparable, valid and reliable semi-factorial stimuli sets. Hence, the first stimuli set manipulated AoA while controlling for the effects of word frequency, imageability, familiarity, concreteness and word length (Morrison, Chappell, & Ellis, 1997; Rossion & Pourtois, 2004). In contrast, the second stimuli set manipulated word frequency while controlling for the effects of AoA, imageability, familiarity, concreteness and word length (Morrison, Chappell, & Ellis, 1997; Rossion & Pourtois, 2004). This was of fundamental importance because these stimuli sets were employed in all of the experiments conducted during this research. The procedure which was followed to establish these stimuli sets is discussed in Chapter 2.

The next aim was to design and implement a robust, systematic and controlled programme of research which investigated the effects of AoA and word frequency in a methodologically consistent manner. Indeed, as outlined in this chapter, previous methodological inconsistencies have often prevented a detailed inspection of the potential loci of AoA and word frequency effects. Therefore, to meet this aim, Chapter 3-8 report six studies consisting of twelve experiments which were adapted to enable the researcher to gradually increase processing demands and incorporate time-sensitive measures. This aim held relevance for each of the objectives identified above. Indeed, it resolves a number of limitations of previous research and presented alternative methodological approaches for investigating AoA and word frequency effects.

The final aim of this thesis was to ensure consistency in the approaches taken during the analyses and interpretation of data. Therefore, similar statistical procedures were implemented throughout this programme of research. This served the important function of facilitating a comparison of effect sizes across the experimental paradigms reported in this thesis and it was particularly salient for meeting the final objective. Indeed, this facilitated the identification of both the number of potential loci and the strength of these effects.

1.3.2 General Hypotheses

As outlined in this chapter, proponents of the PCH would predict significant AoA effects during tasks which require direct lexical access, lexical retrieval and articulation (e.g. during word reading) but not during perceptual or semantic processing. The SH suggests that significant AoA effects in tasks which require that stimuli be processed for meaning (e.g. picture-category verification/falsification) but not during tasks which only require perceptual or lexical processing. In contrast to both of these theories, proponents of the multi-loci perspective would predict significant AoA effects across the perceptual, semantic and lexical processing. According to this theory, the strongest AoA effects should occur during tasks which are characterised by inconsistent mapping between levels of processing (e.g. picture naming). Specific hypotheses are presented for each experimental chapter but based on the critical review of the literature the multi-loci perspective was used to formulate the general hypotheses of this thesis.

The first broad prediction was that AoA would exert a significant effect on visual duration thresholds (VDTs), response times, error/omission rates and total fixation durations when word frequency, imageability, name agreement, visual complexity, orthographic neighbourhood density, concreteness, familiarity and word length were controlled. However, it was also predicted that the magnitude of these effect would vary across experimental paradigms. Indeed, it was predicted that the strongest effects of AoA would be observed during picture naming due to the arbitrary mapping between perceptual, semantic and lexical properties.

The second broad prediction was that word frequency would also exert a significant effect on VDTs, response times, error/omission rates and total fixation durations when AoA, imageability, name agreement, visual complexity, orthographic neighbourhood density, concreteness, familiarity and word length were controlled. However, it was predicted that these effects would be significantly smaller in magnitude than those exerted by AoA. Indeed, due to the inconsistent findings from previous studies which have investigated whether word frequency exert significant effects when

AoA is controlled, it was also predicted that word frequency effects might vary across the experimental paradigms reported in this thesis.

1.4 Chapter Conclusion

While there is substantial evidence for each of the theories reviewed in this chapter, the synthesis of a wide variety of experimental findings and the general consensus observed in the current literature lends the most support to the multi-loci perspective. Indeed, the complex, multifaceted nature of previous results suggests that it is highly unlikely that there is a singular locus which can account for all of these findings. Consequently, the multi-loci principles and predictions need to be explored in greater detail to better enable researchers to identify the potential loci of AoA and word frequency effects within the cognitive system. The literature review identified that methodological adaptations are required to assess the multi-loci theory of AoA and word frequency effects. Indeed, this can be accomplished using a systematic, controlled multi-task investigation which incorporates valid and reliable stimuli sets, time-sensitive measures, consistent procedural elements across experimental paradigms and an appropriate analytical approach. Chapter 2 subsequently outlines how this programme of research was developed and implemented.

Chapter 2: Developing a Methodological Approach

2.1 Chapter Overview

Chapter 2 provides a summary of the methodological bases of this thesis. This is of fundamental importance for meeting the aims and objectives which were identified in Chapter 1, Section 1.3.1. Indeed, this chapter summarises why the particular experimental paradigms were chosen, how valid and reliable semi-factorial stimuli sets were devised and how standardisation was accomplished across very different experimental tasks. This systematic, rigorous and multi-task methodological approach was chosen due to it facilitating the comparison of AoA and word frequency effects across levels of processing. It also made it possible for the studies reported in this thesis to address the methodological limitations which were identified in Chapter 1. For example, the stimuli sets used during this programme of research were identical across this programme of research. Furthermore, the population from which the sample was obtained, recruitment processes, procedural elements and the sequential steps taken during data analyses were also matched across all of the experimental tasks. This facilitated consistency and comparability across the experimental paradigms while also ensuring that the data were standardised at the time of collection.

This research also expanded the bank of available methodologies in AoA research by synthesising eye-tracking and contemporary experimental paradigms. This methodological approach had not previously been extended beyond sentence reading in AoA research. This was despite the potential for this adaptation to provide valuable insights concerning the nature and loci of AoA and word frequency effects. Indeed, eye-tracking was chosen as an appropriate tool due to it providing an accessible, accurate, time sensitive and direct measure of perceptual processing speed which was frequently lacking in earlier studies.

This chapter will demonstrate that the experimental design enabled the researcher to examine the potential loci of AoA and word frequency effects across perceptual processing, semantic processing, direct lexical access, indirect lexical access, lexical retrieval and articulation. Indeed, this programme of research was designed to identify whether AoA and word frequency effects only emerge during one specific level of processing or whether these effects are evident throughout the cognitive system when studies exert a high degree of experimental control. The following sections of this chapter summarise the common methodological features for the following experiments while experiment-specific details are provided within the following chapters.

2.2 Introduction

2.2.1 Perceptual Identification

As discussed in Chapter 1, few studies have investigated the effects of AoA and word frequency during perceptual processing while limiting the role of later stages of processing (Catling, Dent, Johnston & Balding, 2010; Catling, Dent, Preece & Johnston, 2013; Catling, Dent & Williamson, 2008; Catling & Johnston, 2006c, 2009; Dent, Catling & Johnston, 2007; Juhasz & Rayner, 2003; Holmes & Ellis, 2006; Lewis, Chadwick & Ellis, 2002; Spataro, Mulligan, Longobardi & Rossi-Arnaud, 2012; Stewart & Ellis, 2008). Indeed, while significant effects of AoA and word frequency are frequently observed during between-domain and within-domain priming, these experiments also require semantic and lexical levels of processing in order to produce a manual or verbal response upon presentation of the target items (Barry, Hirsh, Johnston, & Williams, 2001; Barry, Johnston, & Wood, 2006; Lewis, Chadwick, & Ellis, 2002; Moore & Valentine, 1998; Yee & Sedivy, 2006). The requirement of a verbal response suggests that lexical processes play a pivotal role in this experimental paradigm and consequently it does not facilitate the isolation and exploration of AoA and word frequency effects during perceptual processing (Rayner, Chace, & Slattery, 2006; Roelofs, 2007; Underwood, Jebbett, & Roberts, 2004; Yee & Sedivy, 2006).

An alternative experimental paradigm for investigating AoA and word frequency effects during perceptual processing is the object classification task; in which participants classify images as an object or non-object. Previous studies have demonstrated that earlier acquired and frequently occurring items can be classified significantly faster and more accurately than later acquired and infrequently occurring items (Holmes & Ellis, 2006; Moore, Smith-Spark & Valentine, 2004; Vitkovitch & Tyrrell, 1995). However, Holmes and Ellis (2006) demonstrated that the effects of AoA which were detected during object/non-object decisions were reduced when articulatory suppression was incorporated in this task. This suggests that object/non-object decisions are also mediated by lexical processing. Furthermore, object/non-object decisions can be reduced to yes/no responses respectively. However, previous studies have suggested that verification and falsification elicit different processing strategies and that falsification is a more cognitive taxing process than verification (Brysbaert, van Wijnendaele & de Deyne, 2000; Chalard & Bonin, 2006; Lewis, 2006; Meyer, Roelofs, & Levelt, 2003; Rayner, Chace, Slattery, & Ashby, 2006; Roelofs, 2007). Consequently, by combining data from trials requiring verification and trials requiring falsification, the findings from object/non-object decisions may be confounded by the response criteria. These limitations suggest that object classification tasks are not necessarily appropriate for research which is attempting to investigate the effects of AoA and word frequency during perceptual processing due to the confounding effects of lexical processing.

In contrast, perceptual identification tasks can facilitate the identification of AoA and word frequency during perceptual processing if the research design incorporates dependent variables which reflect early perceptual processing. For example, visual duration thresholds (VDTs) indicate how long stimuli must be present in the visual field for successful perceptual identification to occur, independent of the objects semantic and lexical components (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006c; Dent, Catling & Johnston, 2007). During this task, the display time of each stimulus increases by specified increments until the participant is able to successfully identify the item using a dichotomous yes/no key press. When the participant is able to identify the object, the corresponding display time is recorded as a VDT. Consequently, this perceptual identification task relies primarily on perceptual processing. While this paradigm has not been widely applied in AoA research, three studies have reported significant effects of AoA on VDTs during this experimental paradigm (Catling & Johnston, 2006c; Catling, Dent, Preece & Johnston, 2013; Dent, Catling & Johnston, 2007). In each of these studies earlier acquired stimuli elicited significantly shorter VDTs than those recorded during the processing of later acquired items. This suggests that participants required more effortful perceptual processing of later acquired items than they did for earlier acquired items. However, research is yet to identify if word frequency also influences VDTs during perceptual identification when

AoA is controlled. Furthermore, none of the studies which have investigated the effects of AoA on VDTs have investigated whether there are any significant differences in decision times during this task. This suggested that further research was required into whether AoA and word frequency exert significant influences on decision times, VDTs and error/omission rates during perceptual identification. Therefore, Chapter 3 presents two semi-factorial experiments which investigated the effects of AoA (Experiment 1a) and word frequency (Experiment 1b) during a perceptual identification task which measured visual duration thresholds.

2.2.2 Eye-Tracking

Although VDTs are useful in regards to investigating whether AoA and word frequency exert significant effects during initial recognition processes, this measure does not facilitate the investigation of AoA and word frequency effects on perceptual processing during tasks which also incorporate semantic and lexical components. Consequently, an additional perceptual measure was required to investigate if AoA and word frequency exerted a significant effect on perceptual processing during more cognitively taxing tasks than perceptual identification. This was accomplished by recording total fixation durations during picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading. Despite the lack of precedence of recording eye-movements during these experimental paradigms in AoA research, previous studies in the field of cognitive psychology have repeatedly demonstrated that eye-movements are a valid and reliable indicator of attention and perceptual processing speeds (Juhasz & Rayner, 2003;

Rayner, Chace, & Slattery, 2006; Roelofs, 2007; Underwood, Jebbett, & Roberts, 2004; Weger & Inhoff, 2006; Yee & Sedivy, 2006).

Indeed, eye-tracking is a direct, non-invasive and temporally accurate measure of moment-to-moment processing which can be used during a wide variety of textual (Juhasz & Rayner, 2003; Rayner, Chace, & Slattery, 2006; Roelofs, 2007) and pictorial experimental paradigms (Underwood, Jebbett, & Roberts, 2004; Yee & Sedivy, 2006). Therefore, it is a useful measure for extending conventional experimental paradigms to explore the loci, nature and time-course of AoA and word frequency effects. For example, total fixation duration on stimuli reflects the automatic allocation of attention and active online processing, whereas reaction times derived from manual or verbal response will reflect some degree of delay between thought and action (Rayner, 1996; Rayner, Chace, & Slattery, 2006; Roelofs, 2007; Underwood, Jebbett, & Roberts, 2004). Eye-tracking can consequently provide a temporally accurate measure, valuable insights concerning perceptual loci of AoA and word frequency effects and assess the validity of the theories presented in Chapter 1. Indeed, as outlined in the previous chapter, perceptual effects of AoA would be inconsistent with the PCH and the SH but it would be compatible with the multi-loci perspective. However, despite the potential benefit of extending AoA research and the precedence of using eye-tracking to assess the influence of various psycholinguistic properties, it has rarely been used when investigating AoA effects (Rayner, 1998; Rayner, Chace, & Slattery, 2006; Rayner & Juhasz, 2004; Roelofs, 2007; Weger & Inhoff, 2006; Yee & Sedivy, 2006).

In one of few studies to combine verification tasks and eye-tracking, Underwood, Jebbett, and Roberts (2004) varied the order of inspection of pictures and sentences and observed that gaze varied according to task difficulty which was manipulated by alternating focussed and general search and detected significantly different patterns of gaze. However, AoA was not the subject of this investigation and it was not controlled. This suggests that AoA may have confounded these findings. Conversely, in an influential study which combined eye-tracking and sentence reading, Juhasz and Rayner (2003) observed independent effects of AoA, word frequency, familiarity, word length and concreteness on eye-movements. This demonstrates that AoA and word frequency can influence perceptual processing speed during complex cognitive tasks such as sentence reading. However, despite these valuable insights, research is yet to investigate the effects of AoA on eye-movements during other experimental tasks.

Indeed, while task complexity can affect performance, eye-movements and the ability of techniques to detect AoA effects it is surprising that research is yet to investigate how AoA and word frequency influence processing speed, response accuracy and eye-movements during other complex cognitive tasks (e.g. Chalard & Bonin, 2006; Meyer, Roelofs, & Levelt, 2003; Rayner, 1998; Rayner, Chace, Slattery, & Ashby, 2007; Roelofs, 2007; Underwood, Jebbett, & Roberts, 2004; Weger & Inhoff, 2006). Consequently, this programme of research addressed this dearth of evidence by incorporating eye-tracking into the picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading experimental paradigms. This enabled the programme of research to investigate if AoA and word frequency exert significant effects on eye-movements during tasks which rely on different aspects of cognitive processing to those previously assessed during sentence reading.

2.2.3 Picture-Category Verification and Falsification

Picture-category verification and falsification tasks are cognitively taxing at a structural to semantic level of processing due to requiring quick and accurate processing of both pictorial and textual properties, access to lemma[26] and lexeme[27] representations for identification, logical processing of items using working memory and the selection of correct responses from a collection of competitors in the semantic network (Barry, Morrison, & Ellis, 1997; Bonin, Chalard, Méot, & Fayol, 2002; Chalard & Bonin, 2006; Holmes, Fitch & Ellis, 2006; Morrison, Hirsh, Chappell, & Ellis, 2002; Stadthagen-González, Damian, Pérez, Bowers, & Martin, 2009; Nazir, Decoppet, & Aghababian, 2003). Hence, this experimental paradigm facilitates the assessment of potential loci at and between perceptual and semantic levels of processing. It also enables the researcher to test the validity of the multi-loci perspective outlined in Chapter 1. Indeed, verification/falsification tasks involve a range of higher-order[28] processes which develop gradually through the processes of maturation and interleaved learning across the lifespan (Ellis & Lambon Ralph, 2000). However, this experimental paradigm has produced mixed results. Therefore, adaptation is required to reduce these limitations and produce valid and reliable results in AoA research.

For example, Holmes and Ellis (2006) argued that Morrison, Ellis and Quinlan (1992) failed to observe AoA effects during a picture categorisation task due to several fundamental methodological limitations. This included the use of multiple regression

[26] A lemma is the abstract meaning attached to a complete word.
[27] A lexeme is a basic unit of meaning that exists regardless of the number of inflectional endings or the number of words it may contain e.g. standing, stands, stood are all derived from the lexeme 'stand'. It is notable that the headwords in dictionaries are all lexemes.
[28] Higher order processes refer to advanced cognitive processes such as reason, logic and problem solving.

with an insufficient number of predictor variables and a small stimulus set; which significantly reduces statistical power and increases the likelihood of Type II error[29]. Morrison, Ellis and Quinlan (1992) also combined data from verification and falsification. As discussed in Section, 2.2.1, this analytical approach may have confounded results because ‘yes’ and ‘no’ decisions are processed differently due to verification being less cognitively taxing than falsification (Brysbaert, van Wijnendaele & de Deyne, 2000; Chalard & Bonin, 2006; Lewis, 2006; Meyer, Roelofs, & Levelt, 2003; Rayner, Chace, Slattery, & Ashby, 2006; Roelofs, 2007). Indeed, when employing a picture-category verification task, Holmes and Ellis (2006, experiment 4) observed AoA effects during verification but not during falsification. This supports theories that different response criteria draw on alternative cognitive processes and are consequently differential susceptibility to AoA effects (Chalard & Bonin, 2006; Lewis, 2006; Meyer, Roelofs, & Levelt, 2003; Rayner, Chace, Slattery, & Ashby, 2006; Roelofs, 2007). However, it is notable that Holmes and Ellis (2006) did not investigate the effects of word frequency, which may have accounted for some of this variability.

Hence, while category verification and falsification tasks are potentially useful experimental techniques which are compatible with multi-loci principles, further investigations are required to investigate the effects of AoA, word frequency and the response criterion on response times, error/omission rates and eye-movements during these tasks. Therefore, Chapter 4 reports two semi-factorial experiments which investigated the effects of AoA (Experiment 2a) and word frequency (Experiment 2b) during picture-category verification/falsification. In these experiments, the effects of AoA and word frequency were considered separately, as were the effects of the

[29] Type II error refers to a false negative in which the researchers have failed to reject an unsupported null hypothesis.

response criteria. This task also enabled the researcher to explore potential loci of AoA and word frequency effects during perceptual and semantic processing. However, while this experimental task can be used to investigate potential loci during perceptual-semantic encoding, this programme of research was also designed to identify if AoA and word frequency influence early lexical processes. Indeed, semantic-lexical encoding can be further differentiated into direct and indirect routes to lexical access (Bakhtiar & Weekes, 2014; Lambon Ralph & Ehsan, 2006). Chapter 5 extends on the principles and findings of Chapter 3 and Chapter 4 to investigate the effects of AoA and word frequency during a picture-name verification/falsification task.

2.2.4 Picture-Name Verification and Falsification

The picture-category verification and falsification paradigm can be expanded to include picture-name verification and falsification tasks. Indeed, in addition to perceptual and semantic processing, this task requires indirect lexical access via the semantic route in order for participants to access the corresponding label in the mental lexicon (Bakhtiar & Weekes, 2014; Lambon Ralph & Ehsan, 2006). Consequently, incorporating both of these experimental tasks into this programme of research enabled differentiation between the effects of AoA and word frequency during perceptual-semantic and semantic-lexical processing respectively. However, very little systematic research has been conducted using this approach and adaptation is required to increase validity and reliability.

For example, as predicted by multi-loci perspectives, Catling and Johnston (2006a) observed significant AoA effects during picture-name verification (experiment 1) and this was significantly lower than the AoA effects observed during picture naming (experiment 3). However, there were a number of limitations with these experiments, including that only the data for verification was analysed, the sample was relatively small (15 undergraduate students) and the effects of word frequency were controlled rather than investigated. Furthermore, other studies have failed to replicate AoA effects in picture-name verification (e.g. Chalard & Bonin, 2006).

Therefore, Chapter 5 presents two semi-factorial experiments which investigated the effects of AoA (Experiment 3a) and word frequency (Experiment 3b) on response times, error/omission rates and total fixation durations during picture-name verification/falsification tasks. In these experiments, the effects of AoA and word frequency were considered separately, as were the effects of the response criteria. This task enabled the research to explore potential loci of AoA and word frequency at perceptual, semantic and lexical levels of processing. Hence, the picture-category verification/falsification and picture-name verification/falsification tasks also facilitated the assessment and comparison of potential loci between perceptual-semantic and semantic-lexical processing respectively. Furthermore, Chapter 6 subsequently expands on these principles to investigate the effects of AoA (Experiment 4a) and word frequency (Experiment 4b) during an immediate picture naming task to explore potential loci during indirect lexical access and lexical retrieval.

2.2.5 Immediate Picture Naming

Immediate picture (or object) naming is a widely used experimental paradigm in AoA literature which can be used to assess loci at the perceptual and semantic levels of processing (Juhasz, 2005). Similar to picture-name verification/falsification, this experimental paradigm relies on indirect lexical access due to the arbitrary mapping between the visually presented stimuli and the corresponding labels stored in the mental lexicon (Bakhtiar & Weekes, 2014; Lambon Ralph & Ehsan, 2006). However, unlike picture-name verification/falsification, it also relies on lexical retrieval and articulation. Hence, picture naming is a natural extension of the picture-name verification/falsification due to it incorporating this additional level of processing. By including both picture-name verification/falsification and immediate picture naming in this programme of research, it was also possible to assess the validity of the arbitrary mapping hypothesis (see Chapter 1, Section 1.2.3). Indeed, if this hypothesis and the multi-loci perspective are correct, AoA effects should be most pronounced during these tasks due to the arbitrary mapping between levels of processing.

It is notable that findings from picture naming studies have usually indicated significant AoA effects (Johnston & Barry, 2006; Juhasz, 2005). For example, in Catling and Johnston's (2009) fourth experiment, 24 participants named 48 objects taken from Barry et al. (2001). The stimuli set consisted of an equal number of early acquired and later acquired items. This stimuli set was also matched for word frequency, familiarity, name agreement, image agreement and visual complexity. Catling and Johnston (2009) identified that items which were learnt earlier in life where named significantly faster and with fewer errors than those which were learnt later in life. However, the effects of word frequency were not investigated during this study. In contrast, Bonin, Chalard, Méot, and Fayol (2002) investigated the effects of AoA and word frequency during written and spoken picture naming. Each of these experiments was conducted with 36 French speaking participants who named 237 pictures from the Snodgrass and Vanderwart (1980) database. They identified that while AoA was a significant predictor of both written and spoken picture naming, word frequency was not. This is also consistent with the findings of Bonin, Peereman, and Fayol (2001). However, it must be noted that the majority of studies investigating the effects of word frequency on picture naming have identified significant effects (Barry et al., 1997; Ellis & Morrison, 1998; Johnston & Barry, 2006; Juhasz, 2005). Interestingly, Bonin, Peereman and Fayol (2001) argue that their measure of word frequency might not accurately reflect the frequency of the items in French. It is also notable that the use of multiple regression in AoA research has been highly criticised due to poor adherence to the paramedic assumption of this test and the increased risk Type I and Type II error (Lewis, 2006; Zevin & Seidenberg, 2002, 2004).

This suggests that while picture naming is a useful technique for assessing AoA effects at perceptual, semantic and lexical levels of processing, adaptation is required to facilitate the identification of potential loci between these levels. Consequently, Chapter 6 presents two semi-factorial experiments which investigated the effects of AoA (Experiment 4a) and word frequency (Experiment 4b) on response times, error/omission rates and total fixation durations during an immediate picture naming task. In these experiments, the effects of AoA and word frequency were considered separately and results were analysed using a 2 (AoA: early vs. late) x 2 (word frequency: high vs. low) analysis of variance. This task enabled the researcher to explore potential loci of AoA and word frequency effects during perceptual processing, semantic processing, indirect lexical access, lexical retrieval and articulation. However, the programme of research was also designed to identify potential loci of AoA during direct lexical access, retrieval and articulation. Therefore, Chapter 7 expands on these principles to investigate the effects of AoA (Experiments 5a) and word frequency (Experiment 5b) during immediate word reading.

2.2.6 Immediate Word Reading

Word reading presents a useful extension of the picture naming experiment. Indeed, this task relies most extensively on perceptual processing, direct lexical access and lexical retrieval based on the transparent mapping between orthography and phonology (Ellis & Morrison, 2000; Johnston & Barry, 2006). This experimental paradigm was chosen due to it enabling the researcher to differentiate between the PCH and the multi-loci perspective. Indeed, as outlined in Chapter 1, the PCH would predict that the strongest effects of AoA would emerge during word reading when lexical properties are the most dominant (Brysbaert, Van Wijnendaele, & De Deyne, 2000; Ghyselinck, Custers, & Brysbaert, 2004; Ghyselinck, Lewis, & Brysbaert, 2004; Gilhooly & Gilhooly, 1980; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989). In contrast, the multi-loci perspective would predict that the strongest effects of AoA would emerge when the mapping between levels of processing is arbitrary, such as in the case of picture naming and picture-name verification/falsification (Ellis, Holmes, & Wright, 2010; Ellis & Lambon Ralph, 2000; Izura & Ellis, 2002, 2004; Lake & Cottrell, 2005; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008).

Indeed, it is notable that Lambon Ralph and Ehsan (2006) identified large AoA effects in picture naming which were not replicated when using the same labels during word reading when word frequency, visual complexity, name agreement and word length were controlled. This is consistent with multi-loci perspective and implies that the AoA effect was stronger when the mapping between the stimuli and the response was arbitrary (such as during pictorial tasks) than it was when it was consistent (such as when there is orthographic input). However, there was a significant limitation of Lambon Ralph and Ehsan’s (2006) study including that they also identified significant word frequency effects during word reading and it is important to remember that connectionist models predict weaker AoA effects when there is a co-occurring effect of word frequency (Ellis & Lambon Ralph, 2000). This suggests that greater control over the stimuli sets may have been beneficial for detecting valid and reliable AoA effects.

It is also notable that Juhasz and Rayner (2003) have previously documented significant effects of AoA, word frequency, familiarity, word length and concreteness on eye-movements during silent sentence reading. However, it must be noted that sentence reading is a very complicated task involving a wide variety of processes which are performed simultaneously. This includes, word recognition, comprehension and memory. Indeed, although comprehension was checked on 10-15% of trials, it is not possible to guarantee that participants read and understood every item. For example, anticipation of the following words often confounds results because individuals tend to skip or only partially read words which are anticipated in order to maximise the speed of reading (Rayner, 1998; Roelofs, 2007). Furthermore, while Juhasz and Rayner (2003) identify that fixating on a stimulus tends to reflect processing, other words may be present in peripheral vision and inhibition of return[30] may also confound results. This suggests that sentence reading may not enable researchers to assess the loci of AoA and word frequency effects due to it not being possible to differentiate between the different processes and systems involved in this task. Therefore, more rigour experimental control is employed in the current programme of research by examining the effects of AoA and word frequency during word reading rather than sentence reading.

Consequently, Chapter 7 presents two semi-factorial experiments investigating the effects of AoA (Experiment 5a) and word frequency (Experiment 5b) on response times, error/omission rates and eye-movements during a word-reading task. In these experiments, words were presented in isolation, the effects of AoA and word frequency were considered separately and results were also analysed using a 2 (AoA: early vs. late) x 2 (word frequency: high vs. low) analysis of variance. This task was designed to enable the researcher to assess potential loci of AoA and word frequency effects during a task which relied upon perceptual processing, direct lexical access, retrieval and articulation. However, while the stimuli sets which were used throughout this programme of research were controlled for familiarity, concreteness, imageability, name agreement, visual complexity, category typicality, orthographic neighbourhood density, number of syllables, number of letters and number of phonemes, they were not controlled for the onset of initial phoneme. Therefore, Chapter 8 reports two semi-factorial experiments which investigated the effects of AoA (Experiment 6a) and word frequency (Experiment 6b) during a delayed picture naming task.

[30] Inhibition of return (IOR) refers to a perceptual mechanism which briefly enhances processing speed and accuracy upon first detection of a stimulus but then impairs the ability to re-attend this stimulus after attention has been disengaged. An example of this would be skim reading a word, identifying that it has not been fully understood and then attempting to return visual attention to his word.

2.2.7 Delayed Picture Naming

Morrison and Ellis (2000) argued that some initial phonemes may be easier to articulate than others; resulting in shorter response times for words beginning with phonemes which are easier to articulate than the response times for words beginning with phonemes which are more difficult to articulate. Furthermore, these effects may be erroneously attributed to the effects of AoA or word frequency if initial phoneme is not adequately controlled during the research process (Catling & Johnston, 2005, 2009; Holmes & Ellis, 2006; Morrison & Ellis, 2000). Indeed, it must be noted that initial phoneme was not controlled during the design of the stimuli sets which were used throughout this programme of research. Therefore, a delayed picture-naming paradigm was developed and employed to investigate if initial phoneme may have confounded verbal response times to stimuli varying in AoA and word frequency (Catling & Johnston, 2005, 2009; Holmes & Ellis, 2006). This task was chosen because it enabled the researcher to investigate whether verbal response times could be confounded by difficulties in initiating articulation (Barry, Hirsh, Johnston & Williams, 2001; Brysbaert, Lange & Van Wijnendaele, 2000; Catling & Johnston, 2005, 2009; Ellis & Morrison, 1998; Gerhand & Barry, 1998; Ghyselinck, Lewis & Brysbaert, 2004; Holmes & Ellis, 2006; Juhasz, 2005; Morrison & Ellis, 1995; Navarrete, Scaltritti, Mulatti & Peressotti, 2013). Indeed, if the results reported in this thesis were confounded by initial phoneme this could potentially exaggerate or mask significant effects of AoA and word frequency thereby distorting the findings reported for immediate picture naming an immediate word reading.

However, AoA and word frequency effects have rarely been observed in delayed naming conditions. For example, Morrison and Ellis (1995) observed significant effects of AoA during immediate word reading but not during delayed word reading when an unpredictable delay was introduced between stimuli presentation and cued response. Furthermore, Morrison and Ellis (1995) also reported that there were no significant effects of word frequency on either immediate or delayed word reading and this pattern of results was also replicated by Catling and Johnston's (2005) multi-task investigation. Similar findings have also been reported during delayed picture naming (Barry, Hirsh, Johnston & Williams, 2001; Catling & Johnston, 2009; Ellis & Morrison, 1998; Holmes & Ellis, 2006). For example, Catling and Johnston (2009), Holmes and Ellis (2006) and Barry, Hirsh, Johnston and Williams (2001) all reported that there were significant effects of AoA during immediate picture naming but that these effects were not replicated during delayed picture naming. In contrast, it is notable that Navarrete, Scaltrirri, Mulatti and Peressotti (2013) observed significant effects of age of acquisition during delayed picture naming. However, this was based on only 20 (25%) of trials compared to the 60 (75%) of trials in which participants performed grammatical-gender decisions and the potential confounding effects of initial phoneme were not considered. Therefore, the majority of studies suggest that the onset of initial phoneme rarely exerts a significant effect on verbal response times when other psycholinguistic properties are controlled.

However, the programme of research reported in this thesis utilised new AoA and word frequency stimuli sets and so further research was required to identify if these items were susceptible to the effects of initial phoneme. Therefore, Chapter 8 reports two semi-factorial delayed picture-naming experiments. Experiment 6a investigated whether initial phoneme confounded response times and error/omission rates for earlier and later acquired items when word frequency, visual complexity, picture-name agreement, familiarity, concreteness, imageability, orthographic neighbourhood density, number of letters, number of phonemes and number of syllables were controlled. Experiment 6b subsequently investigated whether initial phoneme confounded response times and error/omission rates for low and high frequency items when AoA and the other psycholinguistic properties listed above were controlled.

2.3 Summary of Experimental Paradigms

This thesis reports the findings from six studies which consisted of a total of twelve semi-factorial experiments. Each of these experimental paradigms were selected due to facilitating the identification of effects across various stages of cognitive processing. Therefore, Table 2.1 lists the experimental designs which were used during this programme of research and the corresponding levels of processing which are elicited by these tasks.

Table 2.1 Experimental designs and levels of processing

Task	Perceptual	Semantic	Lexical Access	Articulation
Object Recognition	Yes	No	No	No
Picture-Category Verification	Yes	Yes	No	No
Picture-Name Verification	Yes	Yes	Indirect[31]	No
Picture Naming	Yes	Yes	Indirect	Yes
Word Reading	Yes	No	Direct	Yes
Delayed Picture Naming	Yes	Yes	Indirect	Yes

This approach facilitated a more unified and encompassing understanding of the nature and loci of AoA and word frequency effects than has been previously presented. Indeed, it enabled the researcher to evaluate the validity of the predictions made by the PCH, the SH and multi-loci perspectives in controlled laboratory conditions. These predictions are reiterated in Table 2.2. As outlined in Chapter 1, the PCH would predict that the strongest AoA effects would arise during word reading when lexical properties are the most dominant. In contrast the SH would predict that the strongest effects of AoA would emerge during picture-category verification/falsification when semantic properties influence processing speed. Finally, the multi-loci perspective predicts significant effects of AoA across all of the experimental paradigms and levels of processing. However, if the principles of this model are correct, then the strongest effects should be observed during tasks which require arbitrary mapping between levels of processing; such as during picture naming. As discussed in Chapter 1, all of these theories suggest that word frequency may or may not also exert a significant effect during these tasks. Therefore, this programme of research evaluates these theories using

[31] There are two routes to lexical processing. The indirect route occurs via semantic processing and is linked to pictorial task. In contrast, the direct route to lexical processing does not require the understanding of semantics but rather reflects processing when the spelling-to-sound mapping is transparent. This means that the indirect route is typically followed in lexical tasks such as word reading in English.

a series of semi-factorial experiments which each assess different aspects of cognitive processing and investigate the nature and loci of AoA and word frequency effects.

Table 2.2 Key predictions of the theoretical models

	Theoretical Perspective		
Prediction	PCH	SH	Multi-Loci
1	AoA will exert a significant effect on the experimental paradigms which require direct lexical access and articulation (e.g. word reading).	AoA will exert a significant effect on tasks which require semantic processing (e.g. picture-category verification, picture naming verification and picture naming)	AoA will exert a significant influence on performance during all of the experimental paradigms due to processing stimuli which was acquired through interleaved learning
2	AoA and word frequency effects will co-occur because the frequency of occurrence will also determine the entrenchment of the items in the mental lexicon.	AoA and word frequency effects will co-occur because the frequency of occurrence will determine the entrenchment of items in the semantic system.	AoA and word frequency effects can co-occur. However, AoA effects will be most prominent if word frequency does not exert a significant effect.
3	AoA may also influence tasks requiring indirect lexical access if there is a loci during articulation (e.g. picture naming). However, this effect will be smaller in magnitude than that observed during experimental paradigms which require direct lexical access (e.g. word reading).	AoA effects will be strongest during experimental paradigms which require extensive semantic processing (e.g. picture-category verification/falsification).	AoA effects will be largest during experimental paradigms which require the use of arbitrary mapping between levels of processing (e.g. picture naming and picture-name verification/falsification.

2.4 Methodology

2.4.1 Design

A systematic programme of research was designed. The common features of which are presented in the remainder of this chapter while specific details about each experiment are presented in the following chapters. All of the experiments reported in this thesis utilised a quantitative, repeated measure design. Therefore, all participants viewed either early and late acquired items or high and low frequency items. The independent variables were AoA and word frequency. The dependent variables for each experiment are detailed in the following experimental chapters.

2.4.2 Participants

Participant details are presented in each of the experimental chapters. However, all participants were selected using an opportunity sample of undergraduate students, postgraduate students and staff at the University of Worcester and Liverpool John Moore's University. Research participation credits were offered to Psychology students in accordance with departmental policy but no other incentives were provided. Recruitment was undertaken using advertisements on departmental email, e-learning pages, lecture slides, social networks and by word of mouth. A minimum of 20 and maximum of 22 participants were recruited for each of the following experiments. All of the participants were fluent in English as a first language and possessed normal or corrected vision. Furthermore, to avoid the potential of practice effects, participants were only permitted to take part in one of the eight experiments conducted during this programme of research.

Although it could be argued that this was a biased sample due to only sampling from a population within Higher Education, AoA and word frequency effects are highly generalizable across such non-clinical samples (Johnston & Barry, 2006; Morrison, Chappell & Ellis, 1997). For example, despite the AoA and frequency measures used in this research being obtained from groups with different age ranges, socio-economic statuses and ethnic origins there are still significant, valid and reliable AoA effects observed in this research to date (Morrison, Chappell & Ellis, 1997). Indeed, in regards to age differences, commonplace objects and their corresponding labels show little variability across generations. For example, the concrete labels assigned to objects usually retain their meaning over longitudinal periods of time despite the colloquialisms of a language (e.g. slang) frequently changing across generations. This means that a 'drum' will still be referred to as a 'drum' regardless of the age group sampled. In regards to level of education and socio-economic status, it is also notable that there is a formal education system in operation across the United Kingdom. This enables children to be exposed to similar materials regardless of these characteristics. Furthermore, the objects and corresponding names which are used in this research are readily available in the environment and do not require any specialist knowledge or resources. Consequently, these factors are unlikely to influence performance or reflect sampling bias.

However, it must be noted that results may not be generalisable to atypically developing or clinical samples. Indeed, in regards possibly recruiting participants with undisclosed learning difficulties, a sample from Higher Education is unlikely to contain individuals with extreme learning difficulties due to entry requirements. However, participants with minor or moderate impairments may be present in the sample. This issue was managed using a repeated measures design in which participants acted as their own control, thereby reducing the potential influence of participant characteristics (Dancey & Reidy, 2004; Heiman, 2002).

2.4.3 Materials

All stimuli were presented on a desk top subject computer running Microsoft Windows XP Professional with an Intel Pentium 4 2.80 GHz processor, 504 MB ram and 16-inch monitor. All experiments were programmed and presented using E-Prime (Professional, Version 2.0). A keyboard was used for all of the experiments while a hand-held microphone was used during the experiments which required a verbal response. When eye-tracking was used, the dedicated eye-tracker laptop also ran Windows XP Professional with an Intel Pentium M 1.73 GHz processor and 14-inch screen. There were also two observation monitors located next to the eye-tracker laptop displaying eye-movements and screen content in real-time. An Applied Sciences Laboratory Model 504 remote eye-tracker with an auto-focus desk-top mounted eye camera and eye illuminator was also used. The experiment was programmed and presented using E-Prime 2.0 due to this software facilitating a wide variety of experimental techniques and the functions to automatically record responses and response times. Eye-tracking data was collected and condensed using Eyenal 2.66. All data were analysed using the Statistical Package for the Social Sciences.

2.4.3.1 AoA stimuli

To investigate the effects of AoA, appropriate, standardised, valid and reliable stimuli needed to be identified. Consequently, pictorial stimuli were selected from the Rossion and Pourtois' (2004) database which consisted of colourised, standardised versions of the original black and white line drawings developed by Snodgrass and Vanderwart (1980). These images were of common objects such as animals, insects, clothing, household objects and vehicles. These stimuli were chosen because the database was freely available and contained items which corresponded with the Morrison, Chappell, and Ellis' (1997) normative data. Furthermore, this stimuli set was more realistic than the original Snodgrass and Vanderwart's (1980) stimuli due to the inclusion of colour (Rossion & Pourtois, 2004). Notably, this form of stimuli and the normative data have been widely used in AoA research due to their reliability and validity (Morrison, Chappell & Ellis, 1997). Therefore, 259 items were selected due to having a name which corresponded with the Morrison, Chappell, and Ellis' (1997) database. Values extracted from the Morrison, Chappell, and Ellis (1997) database consisted of two objective measures of AoA, two subjective measures of AoA, two measures of word frequency, three measures of word length and one measure of imageability, concreteness, familiarity, visual complexity, picture-name agreement, orthographic neighbourhood density and category typicality (manmade or natural). Items were excluded from the potential stimuli pool if measures of objective AoA (based on when 75% of children typically learn each item) or Celex combined word frequency were not available. Items were also excluded if values exceeding two standard deviations from the mean on any of the normative scales. This ensured that individual items could not significantly inflate or reduce the mean and to facilitate the formation of large, representative and semi-factorial stimuli sets. This resulted in 159 valid pictures available for allocation to the AoA and frequency stimuli sets. The descriptive statistics and comparisons for each stimulus set are provided below and details concerning individual item properties are provided in Appendix A.

A median split on the objective AoA scale representing the age (in months) at which 75% of children acquired the name for each item was used to assign items to the early and late acquisition categories respectively (Morrison, Chappell & Ellis, 1997). After systematically sorting the items according to the listed variables, 34 items were selected to form the early acquired set and an additional 34 items were selected to form the late acquired set. Pearson's product moment revealed that all four measures of age of acquisition were positively correlated, suggesting that the AoA scales could successfully differentiate earlier and later acquired items (see Table 2.3).

Table 2.3 Correlation coefficients for AoA stimuli sets

	Objective AoA (75% in months)	Rated AoA (Likert scale)	Rated AoA (months)
Objective AoA (in months)	.957	.563	.564
Objective AoA (75% in months)		.618	.612
Rated AoA (Likert scale)			.995

Table 2.4 demonstrates that the earlier and later acquired stimuli differed significantly on four measures of AoA provided by Morrison, Chappell, and Ellis (1997) but were matched for all of the remaining variables. This implies that the influence of extraneous variables was controlled; which is not usually accomplished when employing other less rigorous, non-factorial approaches (Lewis, 2006; Zevin & Seidenberg, 2002). It also implies that the sets possess a high degree of concurrent validity due to the early and late acquired sets differing significantly on not one but four measures of age of acquisition. For Experiments 3a (picture-name verification/falsification) and 5a (immediate word reading) the names of these objects were used.

Table 2.4 Means and standard deviations for the AoA stimuli sets

Measure	Early Acquired	Late Acquired	*T*
Objective AoA (in months)	26.62 (15.67)	45.56 (11.56)	4.888*
Objective AoA 75% (in months)	28.53 (14.19)	57.91 (11.91)	9.428*
Rated AoA (7-point scale)	2.05 (.54)	2.42 (.39)	3.262**
Rated AoA (in months)	35.35 (14.92)	45.90 (9.70)	3.459*
Combined Celex frequency	22.68 (23.27)	17.82 (18.27)	.957
Kučera and Francis	21.26 (23.45)	20.29 (17.05)	.188
Familiarity	3.44 (.85)	3.14 (.92)	1.382
Visual complexity	2.80 (.84)	2.91 (.85)	.543
Imageability	6.34 (.26)	6.25 (.28)	1.564
Picture-name agreement	6.59 (.28)	6.51 (.25)	1.259
Category typicality	3.96 (2.69)	3.99 (2.73)	.035
Concreteness	603.32 (21.52)	597.68 (41.66)	.702
Orthographic neighbourhood	9.88 (8.15)	9.70 (7.95)	.935
N letters	5.07 (1.63)	4.79 (1.29)	.754
N phonemes	4.12 (1.49)	3.94 (1.28)	.524
N syllables	1.53 (.75)	1.47 (.67)	.343

Note * $P < .001$, ** $P < .01$

2.4.3.2 Word Frequency Stimuli

To establish the high and low frequency stimuli sets a median split was used to assign items to the respective categories based on the combined Celex frequencies provided by Morrison, Chappell, and Ellis (1997). After systematically sorting the items according to word frequency and subsequently the remaining variables, 34 items were selected to form the low frequency set and 34 items were selected to form the high frequency set (see Table 2.5).

Table 2.5 Means and standard deviations for the word frequency stimuli set

Measure	Low Frequency	High Frequency	*T*
Objective AoA (in months)	39.79 (15.27)	34.42 (15.78)	1.246
Objective AoA 75% (in months)	44.77 (19.95)	39.28 (18.62)	1.172
Rated AoA (7-point scale)	2.26 (.42)	2.12 (.56)	1.243
Rated AoA (in months)	41.49 (11.28)	37.09 (15.29)	1.349
Combined Celex frequency	6.21 (3.47)	42.15 (25.33)	8.196*
Kučera and Francis	9.46 (11.22)	45.30 (30.69)	5.850*
Familiarity	3.18 (.92)	3.45 (.85)	1.230
Visual complexity	2.76 (.91)	2.69 (.80)	.304
Imageability	6.25 (.28)	6.33 (.32)	1.135
Picture-name agreement	6.56 (.27)	6.57 (.28)	.136
Category typicality	3.96 (2.75)	3.98 (2.67)	.023
Concreteness	594.72 (41.75)	600.26 (29.80)	.594
Orthographic neighbourhood	7.91 (6.92)	11.35 (9.08)	.100
N letters	4.94 (1.41)	4.85 (1.60)	.241
N phonemes	3.97 (1.24)	3.88 (1.34)	.281
N syllables	1.50 (.62)	1.32 (.64)	1.161

Note * P < .001

The high and low frequency sets differed significantly for both combined Celex frequency and the Kučera and Francis' (1967) measures but were matched for all of the remaining variables. Pearson's product moment also revealed that the two measures of word frequency were positively correlated suggesting that the frequency scales could successfully differentiate items in the high and low frequency categories, r (61) = .813, $p < .001$. Therefore, the high and low frequency sets were also semi-factorial and matched for thirteen other measures including four measures of AoA reducing the possibility that the measures could be confounded by extraneous variables. For Experiments 3b (picture-name verification/falsification) and 5b (immediate word reading, the names of these objects were used. Details concerning the properties of individual items in the frequency stimuli sets are provided in Appendix B.

2.4.4 Procedure

Specific procedures for each of the experiments conducted during this programme of research are discussed in the respective chapters. However, the overall procedure for the research reported in this thesis consisted of a systematic and rigorously controlled series of twelve semi-factorial experiments and a data synthesis. Each of these experimental paradigms reported in this thesis were purposefully selected by the researcher to explore the potential loci of AoA and word frequency within the cognitive system.

For example, Experiments 1a and 1b (Chapter 3) investigated whether there were any significant effects of AoA and word frequency on VDTs, decision times and error/omission rates during a perceptual identification task. This experimental paradigm was chosen due to it enabling the researcher to investigate whether AoA and word frequency exert significant effects during initial recognition processes. In contrast, Experiments 2a and 2b (Chapter 4) investigated the effects of AoA, the response criteria and word frequency on manual response times, error/omission rates and total fixation durations during picture-category verification/falsification. Consequently, these experiments investigated the potential loci of AoA and word frequency effects during perceptual and semantic processing. Experiments 3a and 3b (Chapter 5) extended these principles using a picture-name verification/falsification task. These experiments also investigated the effects of AoA, the response criteria and word frequency on manual response times, error/omission rates and total fixation durations. However, unlike Experiments 2a and 2b, Experiments 3a and 3b extended the exploration of potential loci to indirect lexical access. Conversely, Experiments 1a – 3b did not explore potential loci of AoA and word frequency during the later stages of lexicalisation and articulation.

Therefore, Experiments 4a and 4b (Chapter 6) consisted of two semi-factorial immediate picture naming experiments. These experiments investigated the effects of AoA and word frequency on verbal response times, error/omission rates and total fixation durations. Hence, Experiments 4a and 4b investigated the potential loci of AoA effects during perceptual processing, semantic processing, indirect lexical access, lexical retrieval and articulation. Furthermore, Experiments 5a and 5b (Chapter 7) consisted of two semi-factorial word reading tasks which investigated the effects of AoA and word frequency on verbal response times, error/omission rates and total fixation durations. Therefore, Experiments 5a and 5b investigated the potential loci of AoA effects during perceptual processing, direct lexical access, lexical retrieval and articulation. However, initial phoneme was not controlled during Experiments 4a-5b. Therefore, Experiments 6a and 6b consisted of two semi-factorial delayed picture naming tasks. This experimental paradigm was introduced to identify whether the results reported for immediate picture naming (Chapter 6) and immediate word reading

(Chapter 7) could be explained by differences between the stimuli sets in regards to the onset of initial phoneme. Finally, Chapter 9 presents a synthesis and re-analysis of the data from all of the experiments which investigated the effects of AoA. In this chapter, the researcher compared the effects of AoA which were observed across the experimental paradigms to identify the most plausible and strongest loci of these effects.

2.4.5 Eye-Tracking Calibration

When eye-tracking was used during Experiments 2a-5b, the eye-tracker was placed in front of the monitor of the subject computer without any obstructions to the participants' view of the screen and in direct line of sight of the participant's right eye. Participants were seated approximately 60cm. from the monitor of the subject computer. A verbal introduction was provided into the nature of the picture-category verification task and verbal consent was obtained. Before the start of the experiment, participants were presented with a 9-point calibration grid (3 rows x 3 columns running left to right) and were instructed to look at the centre of the screen while the experimenter adjusted the camera position and settings for optimal performance. Participants were then asked to look at each of the nine points consecutively while calibration was completed by the experimenter on the eye-tracker laptop.

2.4.6 Ethics

Ethical approval for this research was obtained from the Institute of Health and Society Research Ethics Committee prior to the commencement of the programme of research. All participants received full disclosure concerning the aims and objectives of the research, the procedure and the requirements on participants, how their data would be used, their rights to withdraw from the experiment without penalty and their right to remove their data within an allotted time of two weeks using their participant number. Verbal informed consent was obtained for all participants prior to the start of the experiment. Participant numbers were assigned to ensure confidentiality and anonymity. None of the experiments exceeded twenty minutes and none of the stimuli were of a sensitive or harmful nature. A full debriefing was also provided which allowed participants to ask questions and ensure they fully understood the experiment. Therefore, there was no foreseeable short-term or long-term harm to participants.

2.5 Data Preparation

Errors, omissions and all values exceeding two standard deviations from the mean of each measure obtained were excluded from the subsequent analyses. This was in accordance with good practice when cleaning data and it is also consistent with the convention of research into the effects AoA (Field, 2005; Lewis, 2006; Zevin & Seidenberg, 2002). Indeed, data were trimmed to two standard deviations from the mean to reduce the possibility that extreme scores would distort the mean and therefore produce misleading and unreliable results (Dancey & Reidy, 2004; Tabachnick & Fidell, 2007). As the research is concerned with average performance, the trimmed data would not add to the analyses but would detract from reliability if retained. This practice is particularly useful in improving the quality and integrity of data sets because an unrealistically short response suggests that the participants did not follow the instructions while an inflated score may reflect distraction rather than a processing disadvantage. It also improves distribution and homogeneity of variance; facilitating the use of stronger parametric analyses than if the data were skewed or contain a significant amount of variance. Indeed, extreme scores and data beyond two standard deviations can either mask significant effects or give the false impression that there is an effect based on a comparison of distorted both parametric and non-parametric analyses (Dancey & Reidy, 2004; Field, 2005; Heiman, 2002).

Subsequently, average response times and error/omission rates were calculated by-subject and by-item for all of the following experiments. VDTs were also recorded by-subject and by-item during Experiments 1a and 1b; as measured by the display time which corresponded to successful recognition. Furthermore, when eye-tracking was used, total fixation durations were also calculated by-subject and by-item based on the total amount of time participants spent fixating on the specific region in which the critical items were presented while they remained on the screen. The purpose of analysing results by-subject and by-item was to ensure that any observed effects were reliable and valid; rather than the result of confounding participant variables or item effects. For example, if an effect was observed by-subject but not by-item, this may reflect participant idiosyncrasies. In contrast, if an effect was observed by-item but not by-subject, this may imply than a particular critical item was more difficult to process than other critical items. Preliminary assumption testing was also conducted for all of the following experiments using graphs, descriptive statistics and z-scores. This revealed that after data cleaning the data were free from extreme scores, relatively normally distributed and homogeneous. Therefore, this enabled the use of parametric analyses which are powerful and robust statistical tests.

2.6 Chapter Conclusion

Chapter 2 provided a concise overview of the common methodological features of the studies reported in the following six experimental chapters. These experiments investigate the effects of AoA and word frequency in a systematic, valid, reliable and controlled manner which facilitates a comparison of effects across studies. Indeed, all of the experiments reported in this thesis draw on the same semi-factorial stimuli sets, common procedural elements and analytical techniques. Each of the following six chapters contains a brief introduction which is specific to the experimental paradigm, a summary of the methodology, a comprehensive overview of the results and a discussion of the findings. Chapter 9 reports a synthesis and reanalysis of the response times recorded during perceptual identification, picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading. This enabled the comparison of the effect sizes exerted by AoA and an exploration of the potential locus – or loci – of these effects. The general discussion presented in Chapter 10 subsequently contextualises and evaluates the insights provided by the twelve experiments and comparison of effect sizes reported in this thesis.

Chapter 3: Perceptual Identification

3.1 Chapter Overview

Chapter 3 reports two semi-factorial experiments which investigated if AoA (Experiment 1a) and word frequency (Experiment 1b) exerted significant effects on decision times (ms), VDTs and error/omission rates during an adaptation of the perceptual identification task. This experimental paradigm was chosen due to it enabling the researcher to investigate if there are loci of AoA and word frequency effects during initial recognition processes. Indeed, previous research has demonstrated that this experimental paradigm is effective in reducing the confounding influence of semantic and lexical processing (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006c; Dent, Catling & Johnson, 2007). Experiment 1a revealed significant main effects of AoA on decision times, VDTs and error/omission rates when word frequency, word length, imageability, concreteness, familiarity, visual complexity, orthographic neighbourhood density and name agreement were controlled. Therefore, earlier acquired items could be perceived and processed significantly faster than later acquired items and earlier acquired items also elicited fewer errors/omissions. This suggests that there may be a locus or loci of AoA during initial recognition processes. In contrast, Experiment 1b revealed that there were no significant effects of word frequency on decision times, VDTs or error/omission rates when AoA, word length, imageability, concreteness, familiarity, visual complexity, orthographic neighbourhood density and name agreement were controlled. Therefore, high frequency items did not elicit a processing advantage over low frequency items during this perceptual identification task. These results are contextualised in the chapter discussion.

3.2 Introduction to Experiments 1a and 1b

As discussed in Chapter 1 and Chapter 2, studies have only recently begun to investigate if there are significant effects of AoA during perceptual processing. Indeed, as discussed in Chapter 1, before the development of the multi-loci perspective, the focus of AoA research was to test the predictions of the PCH and the SH. Neither the PCH nor the SH incorporated perceptual processing in their theoretical perspectives so the focus of earlier research was primarily to identify significant effects during semantic and lexical processing (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Brysbaert, Van Wijnendaele, & De Deyne, 2000; Garlock, Walley, & Metsala, 2001; Gilhooly & Gilhooly, 1980; Moore, Smith-Spark, & Valentine, 2004; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989). In contrast, proponents of the multi-loci perspective argued that AoA and word frequency effects are pervasive throughout the cognitive system and an emergent property of any learning schedule which resulted in interleaved acquisition of information (Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Hirsh, Morrison, Gaset, & Carnicer, 2003; Izura et al., 2011; Lake & Cottrell, 2005; Morrison, Hirsh, Chappell, & Ellis, 2002). This suggests that AoA and word frequency may also exert significant effects during initial recognition processes.

For example, several studies have investigated if there are significant effects of AoA during object classification tasks. This experimental paraidigm entails the classification of pictorial stimuli as objects or non-objects based on the visual properties of the stimuli (Barry & Johnston, 2006; Holmes & Ellis, 2006; Juhasz, 2005; Moore, Smith-Spark & Valentine, 2004; Vitkovitch & Tyrrell, 1995). For example, Vitkovitch and Tyrrell (1995) observed that earlier acquired items can be classified as objects or non-objects significantly faster than later acquired items when word frequency was controlled. These results have subsequently been replicated by Holmes and Ellis (2006) and Moore, Smith-Spark and Valentine (2004). However, Holmes and Ellis (2006) demonstrated that the effects of AoA were significantly reduced when atypical objects were included in the stimuli set and when articulatory suppression was incorporated into the object classification task. This suggests that object/non-object decisions are mediated by both typicality and lexical processing. Furthermore, as discussed in Chapter 2, Section 2.2.1, object/non-object decisions are equivalent to participants producing dichotomous yes (object) or no (non-object) decisions (Lewis, 2006; Rayner, Chace, Slattery, & Ashby, 2006; Roelofs,2007). This methodological approach is counterintuitive to identifying valid and reliable effects of AoA during perceptual processing because by combining data from trials requiring verification and data from trials requiring falsification, the response criteria can confound response times (Brysbaert, van Wijnendaele & de Deyne, 2000; Chalard & Bonin, 2006; Lewis, 2006; Meyer, Roelofs, & Levelt, 2003; Rayner, Chace, Slattery, & Ashby, 2006; Roelofs, 2007). Therefore, this suggests that object classification tasks do not reliably facilitate the isolation and identification of AoA and word frequency effects during initial recognition processes.

An alternative methodology which enables researchers to identify significant effects of AoA and word frequency during the initial recognition of visually presented stimuli is the perceptual identification task. In this experimental paradigm, participants are required to identify objects which are presented for increasing but brief intervals of time. The display times which facilitated successful identification of the objects are then recorded as the VDTs. As outlined in Chapter 2, Section 2.2.1, recording VDTs enables researchers to identify how long stimuli must be present in the visual field before successful perceptual identification can occur, independent of the semantic or lexical components of the stimuli (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006c; Dent, Catling & Johnston, 2007). Indeed, research has recently demonstrated that AoA exerts a significant effect on VDTs during perceptual identification tasks (Catling & Johnston, 2006c; Catling, Dent, Preece & Johnston, 2013; Dent, Catling & Johnston, 2007). For example, Catling, Dent, Preece and Johnston (2013) trained participants to recognise symmetrical, three dimensional, computer generated images called ‘Greebles’. These stimuli were assigned nonsense names in the form of trigrams (e.g. Tuv, Mip, Kol). Consistent with a typical learning curve, the training procedure was interleaved so that items were gradually added to the stimuli pool and cumulative frequency was matched across the earlier and later acquired stimuli sets. Following training, participants completed an immediate picture naming task (Experiment 1) or a perceptual identification task (Experiment 2). Catling, Dent, Preece and Johnston (2013) identified that there were significant effects of AoA on both the verbal response times produced during Experiment 1 and the VDTs which were recorded during Experiment 2. Therefore, earlier acquired items could be named significantly faster than later acquired items and they would also be identified after significantly shorter display times than later acquired items. Similar results have also been observed by Dent, Catling and Johnston (2007) and Catling and Johnston (2006c). Therefore, in each of these studies earlier acquired stimuli elicited significantly shorter VDTs than those recorded during the processing of later acquired items. This suggests that participants required more effortful perceptual processing of later acquired items than they did for earlier acquired items. However, as discussed in Chapter 2, Section

2.2.1, further research is needed to identify if word frequency also influences VDTs when AoA is controlled. Indeed, all of the previous studies which have investigated the effects of AoA using this experimental paradigm have controlled – rather than investigated – the effects of word frequency (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006c; Dent, Catling & Johnston, 2007). Furthermore, none of the previous studies which have investigated the effects of AoA on VDTs during the perceptual identification task have investigated if there are also significant effects of AoA on decision times during this experimental paradigm. This suggests that further research is required to identify if AoA and word frequency exert significant effects on decision times, VDTs and error/omission rates during perceptual identification. Therefore, Chapter 3 reports two semi-factorial experiments which investigated if there were significant effects of AoA (Experiment 1a) and word frequency (Experiment 1b) during an adaptation of the perceptual identification task.

3.2.1 Hypotheses for Experiment 1a

Three hypotheses were formulated for Experiment 1a based on the insights provided by the literature reported in Chapter 1 and the multi-loci perspective:

- Earlier acquired items will elicit significantly shorter visual duration thresholds than later acquired items.
- Earlier acquired items will elicit significantly shorter decision times than later acquired items

- Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items.

3.2.2 Hypotheses for Experiment 1b

Three hypotheses were also formulated for Experiment 1b based on the literature reported in Chapter 1 and the multi-loci perspective:

- High frequency items will elicit significantly shorter visual duration thresholds than low frequency items.
- High frequency items will elicit significantly shorter decision times than low frequency items.
- High frequency items will elicit significantly fewer errors/omissions than low frequency items.

3.3 Methodology for Experiment 1a

3.3.1 Design

Experiment 1a utilised a repeated measures design. Therefore, the independent variable was AoA (early vs. late acquired). The first dependent variable was decision time. This was operationalised as the difference between when the screen containing the text ‘Can you name the object?’ was presented and when the participant pressed the ‘Y’ key. The second dependant variable was VDTs. This was operationalised as the display time which facilitated successful perceptual recognition. The third dependent variable was error/omission rate as operationalised as the total number of times the participants provided an incorrect answer, failed to produce a response while the critical item remained on the screen or produced a response which was beyond two standard deviations from the mean.

3.3.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 1a, participants consisted of 20 (4 males and 16 females) undergraduate and postgraduate students. Participants ranged from 18 to 39 years of age with a mean age of 23 (5.97) years.

3.3.3 Materials

The materials were identical to those discussed in Chapter 2, Section 2.4.3.1. However, in addition to these materials, for Experiment 1a and visual mask was also designed by overlaying images from the Rossion and Pourtois (2004) database. None of the images which were used for the visual mask were present in the stimuli sets.

3.3.4 Procedure

Standardised written instructions were presented on the screen. When participants indicated that they had read and understood the instructions, they were asked to press any key to complete 6 practice trials. The 68 critical trials followed automatically. For each trial, a fixation cross was presented in the centre of the screen for 2000ms followed by a visual mask for 2000ms, the target item for varying intervals as detailed below and the visual mask for a further 2000ms. After the second mask, recognition was cued by the question ‘’Can you identify the object?’’. On the first display the target item was presented for 60ms. Participants pressed the Y key if they could identify the object and they subsequently proceeded to the next trial. However, participants pressed the N key if they could not identify the object and needed to see the item again for up to 120ms (with increments of 15ms). There was an inter-trial interval of 4000ms; during which time participants stated the name of the object they had just identified for the purposes of manually recording errors. The order in which objects were presented was randomised to reduce practice effects. After completing the experiments participants were provided with a verbal and standardised written debriefing regards the aims and objectives of the experiment.

3.4 Results for Experiment 1a

3.4.1 Data Preparation

Data preparation procedures were discussed in Chapter 2, Section 2.5.

3.4.2 Analysis of Decision Times

Table 3.1 presents the average decision times (ms) which were elicited when participants processed earlier and later acquired items. This demonstrates that on average decision times were shorter when participants processed earlier acquired items (M_1 = 522.42, *SD* = 260.12; M_2 = 504.87, *SD* = 70.46) compared to when they processed later acquired items (M_1 = 649.26, *SD* = 296.72; M_2 = 647.79, *SD* = 98.40). This suggests that AoA exerted an influence on decision times.

Table 3.1 Average decision times and error/omission rates for Experiment 1a

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Early acquired decision time	504.87 (70.46)	522.42 (260.12)
Late acquired decision time	647.79 (98.40)	649.26 (296.72)
Early acquired error/omission rates	2.29 (1.64)	3.95 (3.79)
Late acquired error/omission rates	3.88 (1.65)	6.65 (3.42)

Consequently, decision times for earlier and later acquired items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed a significant main effect of AoA on decision times by-subject and by-item, which accounted for 31% and 55% of the variance respectively; F_1 (1, 19) = 8.454, $p < 0.01$, partial η^2 = .308; F_2 (1, 33) = 40.595, $p < 0.001$, partial η^2 = .552. Therefore, decision times were significantly shorter when participants were identifying earlier acquired items compared to when they were identifying later acquired items. This demonstrates that AoA exerted a significant effect on decision times during the perceptual identification task and this finding suggests that AoA influences initial recognition processes.

3.4.3 Analysis of Error/Omission Rates

Table 3.1 also presents the descriptive statistics for average error/omission rates produced for earlier and later acquired items during perceptual identification. This demonstrates that participants made fewer errors while processing earlier acquired items (M_1 = 3.95, *SD* = 3.79; M_2 = 2.29, *SD* = 1.64) compared to when they processed later acquired items (M_1 = 6.65, *SD* = 3.42; M_2 = 3.88, *SD* = 1.65). This suggests that earlier acquired items were less prone to error than later acquired items.

Error/omission rates were subsequently analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This revealed a significant main effect of AoA on error/omission rates by-subject or by-item which accounted for 27% and 33% of the variance respectively; F_1 (1, 19) = 6.922, $p < .05$, partial $\eta^2 = .267$; F_2 (1, 33) = 15.879, $p < .001$, partial $\eta^2 = .325$. This suggests that in addition to eliciting slower decision times, later acquired items were also significantly more susceptible to error than earlier acquired items during perceptual identification. Therefore, in addition to the significant effect on decision times, AoA also exerted a significant effect on response accuracy during initial recognition processes.

3.4.4 Analysis of Visual Duration Thresholds

Table 3.2 presents the average VDTs (ms) for earlier and later acquired items. This demonstrates that participants could recognise earlier acquired items after shorter display times (M_1 = 63.72, *SD* = 4.98; M_2 = 63.79, *SD* = 2.17) than later acquired items (M_1 = 69.79, *SD* = 10.46; M_2 = 68.92, *SD* = 4.00). This suggests that earlier acquired items can be identified successfully after shorter display times than those required for the successful identification of later acquired items.

Table 3.2 Average visual duration thresholds for Experiment 1a

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Early acquired recognition time	63.79 (2.17)	63.72 (4.98)
Late acquired recognition time	68.92 (4.00)	69.79 (10.46)

VDTs for earlier and later acquired items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed a significant main effect of AoA on VDTs by-subject and by-item, which accounted for 31% and 60% of the variance respectively; F_1 (1, 19) = 8.579, $p < 0.01$, partial $\eta^2 = .311$; F_2 (1, 33) = 48.404, $p < 0.001$, partial $\eta^2 = .595$. Therefore, earlier acquired items could be identified after significantly shorter display times than later acquired items. This suggests that AoA exerted a significant effect during perceptual processing.

3.5 Methodology for Experiment 1b

3.5.1 Design

Experiment 3b utilised a repeated measures design. Therefore, the independent variable was word frequency (high vs. low). The dependent variables were identical to those of Experiment 1a.

3.5.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 1b, participants consisted of 20 (5 males and 15 females) undergraduate and postgraduate students. Participants ranged from 18 to 38 years of age and with a mean age of 22.40 (6.25) years.

3.5.3 Materials

The general materials and word frequency stimuli sets for Experiment 1b were identical to those discussed in Chapter 2, Section 2.4.3.2.

3.5.4 Procedure

The procedure was identical to that used in Experiment 1a.

3.6 Results for Experiment 1b

3.6.1 Data Preparation

Data preparation processes were discussed in Chapter 2, Section 2.5.

3.6.2 Analysis of Decision Times

Table 3.3 presents the descriptive statistics for decision times (ms) which were elcitited by low and high frequency items. Therefore, decision times were longer for low frequency items (M_1 = 628.23, *SD* = 228.08; M_2 = 619.16, *SD* = 79.45) than for high frequency items (M_1 = 599.22, *SD* = 205.00; M_2 = 593.68, *SD* = 65.79). This suggests that word frequency may have exerted a significant effect on decision times.

Table 3.3 Average decision times and error/omission rates for Experiment 1b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency decision time	619.16 (79.45)	628.23 (238.08)
High frequency decision time	593.68 (65.79)	599.22 (205.00)
Low frequency error/omission rates	3.03 (2.53)	5.15 (2.85)
High frequency error/omission rates	2.56 (1.54)	4.40 (3.74)

Therefore, decision times for low and high frequency items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed that there were no significant effects of word frequency on decision times by-subject or by-item, F_1 (1, 19) = 1.036, $p > .05$, partial $\eta^2 = .052$; F_2 (1, 33) = 1.994, $p > .05$, partial $\eta^2 = .057$. Therefore, word frequency did not exert a significant effect on decision times during perceptual identification.

3.4.3 Analysis of Error/Omission Rates

Table 3.3 also presents the descriptive statistics for average error/omission rates produced for low and high frequency items during perceptual identification. This demonstrates that there were more errors/omissions for low frequency items (M_1 = 5.15, *SD* = 2.85; M_2 = 3.03, *SD* = 2.53) than there were for high frequency items (M_1 = 4.40, *SD* = 3.74; M_2 = 2.56, *SD* = 1.54). This suggests that low frequency items may have been more susceptible to errors than high frequency items.

Error/omission rates were also analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This revealed that there was no significant effect of word frequency on error/omission rates by-subject or by-item; F_1 (1, 19) = 1.245, $p > .05$, partial η^2 = .061; F_2 (1, 33) = .743, $p > .05$, partial η^2 = .022. This suggests that word frequency did not exert a significant effect on error/omission rates during perceptual identification.

3.4.4 Analysis of Visual Duration Thresholds

Table 3.4 presents the average VDTs (ms) for low and high frequency items. This demonstrates that VDTs were similar for low frequency (M_1 = 61.74, *SD* = 2.04; M_2 = 61.93, *SD* = 3.76) and high frequency (M_1 = 61.11, *SD* = .93; M_2 = 61.18, *SD* = 1.45) items. This suggests that low frequency items did not require longer presentation times for successful recognition than high frequency items.

Table 3.4 Average visual duration thresholds for Experiment 1b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency VDT	61.93 (3.76)	61.74 (2.04)
High frequency VDT	61.18 (1.45)	61.11 (.93)

The VDTs for low and high frequency items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This confirmed that there were no significant effects of word frequency on VDTs by-subject and by-item; F_1 (1, 19) = 3.899, $p > .05$, partial $\eta^2 = .15$; F_2 (1, 33) = 1.416, $p > .05$, partial $\eta^2 = .041$. Therefore, participants the VDTs elicited by low frequency items were not significantly longer than those elicited by high frequency items. These findings demonstate that word frequency did not exert significant effects on decision times, VDTs or error/omission rates during initial recognition processes.

3.7 Discussion of Results for Experiments 1a-1b

Chapter 3 reported two semi-factorial experiments which investigated the effects of AoA (Experiment 1a) and word frequency (Experiment 1b) on decision times, error/omission rates and VDTs during a perceptual identification task. As discussed in Chapter 3, Section 3.2, previous studies which have employed similar experimental paradigms have only investigated the effects of AoA on decision times and error/omission rates (Holmes & Ellis, 2006; Moore, Smith-Spark & Valentine, 2004; Vitkovitch & Tyrrell, 1995) or the effects of AoA on VDTs and error/omission rates (Catling, Dent, Preece & Johnston, 2009; Catling & Johnston, 2006c; Dent, Catling & Johnston, 2007). Consequently, it was argued that further research was required to identify if VDTs and decision times diverge or converge during perceptual processing and whether word frequency also exerts significant effects on decision times, VDTs and error/omission rates during perceptual identification. Therefore, Experiment 1a and Experiment 1b were the first to investigate if AoA and word frequency influenced VDTs, decision times and error/omission rates using this experimental paradigm.

Table 3.5 demonstrates that the hypotheses which were presented for Experiment 1a have been supported. Indeed, Experiment 1a revealed significant effects of AoA on decision times, error/omission rates and VDTs during an adaptation of the perceptual identification task. The significant effect of AoA on VDTs implies that earlier acquired items could be recognised after significantly shorter display times than those required for the successful recognition of later acquired items (Catling, Dent, Preece & Johnston, 2009; Catling & Johnston, 2006c; Dent, Catling & Johnston, 2007). Furthermore, the significant effects of AoA on decision times and error/omission rates also suggested that responses were significantly faster for earlier acquired items than for later acquired items. This lends support to the proposition that there is a locus – or loci – of AoA effects prior to semantic and lexical processing (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006c, 2009; Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Juhasz & Rayner, 2003, 2006).

Table 3.5 Implications for the hypotheses of Experiment 1a

Hypothesis	Evidence
Earlier acquired items will elicit significantly shorter decision times than later acquired items.	Supported
Earlier acquired items will elicit significantly shorter visual duration thresholds than later acquired items.	Supported
Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items	Supported

Indeed, these findings are inconsistent with the predictions of the PCH and the SH which were discussed in Chapter 1, Section 1.2.1 and Section 1.2.2 respectively (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Brysbaert, Van Wijnendaele, & De Deyne, 2000; Garlock, Walley, & Metsala, 2001; Ghyselinck, Custers, & Brysbaert, 2004; Ghyselinck, Lewis, & Brysbaert, 2004; Gilhooly & Gilhooly, 1980; Moore, Smith-Spark, & Valentine, 2004; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989). For example, VDTs record the amount of time a stimulus must be present in the visual field for successful recognition to occur. Consequently, this measure reflects the processing of visual components of stimuli, rather than the semantic or lexical components of stimuli (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006a; Dent, Catling & Johnston, 2007). However, these findings offer support for the multi-loci perspective which was discussed in Chapter 1, Section 1.2.3 (Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Hirsh, Morrison, Gaset, & Carnicer, 2003; Izura et al., 2011; Lake & Cottrell, 2005; Morrison, Hirsh, Chappell, & Ellis, 2002; Stewart & Ellis, 2008). Indeed, proponents of the multi-loci perspective argue that the effects of AoA are pervasive throughout the cognitive system; including during initial recognition processes. Therefore, the findings from Experiment 1a suggest that AoA does exert a significant effect during perceptual processing and this conclusion also supports previous studies which have documented significant effects of AoA prior to semantic and lexical processing.

For example, Experiment 1a successfully replicated previous studies which have documented significant effect of AoA on VDTs; as previously reported by Catling, Dent, Preece and Johnston (2013), Catling and Johnston (2006c) and Dent, Catling & Johnston (2007). However, Experiment 1a also expanded on the principles and findings of previous studies by investigating and documenting significant effects of AoA on decision times and error/omission rates in conjunction with the significant effect of AoA on VDTs. Previous studies have also documented significant effects of AoA on response times during object classification (Holmes & Ellis, 2006; Moore, Smith-Spark & Valentine, 2004), eye-movements during sentence reading (Juhasz & Rayner, 2003, 2006), response times during between and within domain priming (Anderson, 2008; Barry, Hirsh, Johnston & Williams, 2001; Barry Johnston & Wood, 2006; Catling & Johnston, 2006b; Lewis, 2006; Lewis, Chadwick & Ellis, 2002) and response times during face recognition (Bonin, Perret, Méot, Ferrand, & Mermillod, 2008; Lake & Cottrell, 2005; Richards & Ellis, 2008; Smith-Spark & Moore, 2009). When interpreted in context, these findings suggest that earlier acquired items may begin to gain a processing advantage over later acquired items during initial recognition processes. However, further research is required to identify if these effects are replicable in other samples, when using alternative perceptual measures and when utilising experimental paradigms which also rely on later stages of processing.

In contrast to the findings from Experiment 1a, Experiment 1b revealed that word frequency did not exert a significant effect on decision times, VDTs or error/omission rates when AoA, word length, imageability, visual complexity, familiarity, orthographic neighbourhood size, picture-name agreement and concreteness were controlled. The implications for the hypotheses which were proposed for Experiment 1b are presented in Table 3.6.

Table 3.6 Implications for the hypotheses of Experiment 1b

Hypothesis	Evidence
High frequency items will elicit significantly shorter decision times than low frequency items	Not Supported
High frequency items will elicit significantly shorter visual duration thresholds than low frequency items.	Not Supported
High frequency items will elicit significantly fewer errors/omissions than low frequency items	Not Supported

These findings suggest that word frequency did not exert a significant effect on processing speed or response accuracy during initial recognition processes when AoA, familiarity, concreteness, imageability, picture-name agreement, visual complexity, orthographic neighbourhood size and word length were controlled. Therefore, high frequency items did not elicit a processing advantage over low frequency items during the perceptual identification task. However, as discussed in Chapter 1, previous studies have repeatedly documented significant effects of AoA in the absence of any significant effects of word frequency (Barry, Johnston, & Wood, 2006; Brysbaert & Ghyselinck, 2006; Lambon Ralph & Ehsan, 2007; Law, Wong, Yeung, & Weekes, 2008; Law & Yeung, 2010; Raman, 2006; Shibahara, Zorzi, Hill, Wydell, & Butterworth, 2003). This dissociation is frequently observed when semi-factorial designs have been employed; possibly due to this methodological approach increasing experimental control, inhibiting interaction between variables and reducing that unexplained variance (Barry & Johnston, 2006; Juhasz, 2005; Lewis, 2006; Zevin & Seidenberg, 2002, 2004).

Indeed, while proponents of the multi-loci perspective have argued that AoA and word frequency effects can co-occur throughout the cognitive system, this is usually observed when variables have been permitted to co-vary (Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Hirsh, Morrison, Gaset, & Carnicer, 2003; Izura et al., 2011; Lake & Cottrell, 2005; Lewis, 2006; Morrison, Hirsh, Chappell, & Ellis, 2002;

Stewart & Ellis, 2008; Zevin & Seidenberg, 2002, 2004). In contrast, the stimuli sets which were used during this programme of research were rigorously controlled and matached for a wide variety of extraneous variables (see Chapter 2, Section 2.4.3.1 and Section 2.4.3.2). This suggests that the methodological approach which was adapted during this programme of research may have masked any significant effects of word frequency during this experimental paradigm.

However, previous studies have documented significant but independent effects of word frequency and AoA on perceptual measures. Indeed, Juhasz and Rayner (2003, 2006) have previously documented significant effects of both AoA and word frequency on eye-movements during sentence reading. This suggests that effects of AoA and word frequency may co-occur during perceptual processing if studies obtain time-sensitive measures and utilise experimental tasks which require more effortful processing than perceptual identification (Barry & Johnston, 2006; Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2009; Juhasz & Rayner, 2003, 2006). However, as discussed in Chapter 2, Section 2.2.2, research is yet to identify if AoA and word frequency exert significant effects on eye-movements during other experimental paradigms which are frequently used in AoA research. Indeed, as discussed in Chapter 1, Section 1.3.1, one of the objectives of programme of research was to explore and differentiate between effects of AoA and word frequency which are observed during perceptual, semantic and lexical processing. Therefore, further research is required to investigate if AoA and word frequency exert significant effects on perceptual processing during tasks which also incorporate elements of semantic and lexical processing.

Consequently, Chapter 4 reports two semi-factorial experiments which investigated the effects of AoA and word frequency on manual response times, error/omission rates and total fixation durations during a picture-category verification/falsification task. This experimental paradigm was chosen because it enabled the researcher to investigate whether AoA and word frequency exerted significant effects during a task which relied on perceptual processing and semantic processing. Therefore, including both a perceptual identification task and a picture-category verification/falsification task in this programme of research enabled differentiation between perceptual and semantic effects of AoA and word frequency. To ensure results were comparable across experimental paradigms, the stimuli set, procedural elements and analytical processes are identical to those reported for Experiment 1a and Experiment 1b.

3.8 Chapter Conclusion

The experiments reported in Chapter 3 were the first to investigate if AoA and word frequency exerted significant effects on decision times, VDTs and error/omission rates during a perceptual identification task. Indeed, while previous studies have reported significant effects of AoA on decision times during object classification (Holmes & Ellis, 2006; Moore, Smith-Spark & Valentine, 2004), or significant effects of AoA on VDTs during perceptual identification (Catling, Dent, Preece & Johnston, 2013; Dent, Catling & Johnston, 2007; Catling & Johnston, 2006c), Experiment 1a was the first to record decision times, VDTs and error/omission rates. Furthermore, Experiment 1b was also the first study to investigate if word frequency exerted a significant effect on decision times, VDTs and error/omission rates during perceptual identification when AoA was controlled. Indeed, previous studies which investigated the effects of AoA during perceptual identification did not investigate the effects of word frequency (Catling, Dent, Preece & Johnston, 2013; Dent, Catling & Johnston, 2007; Catling & Johnston, 2006c). Therefore, Experiments 1a and 1b expand on the principles and findings of previous studies to investigate whether AoA and word frequency exert significant effects during initial recognition processes.

The findings reported in this chapter demonstrated that AoA exerted a significant effect on decision times, VDTs and error/omission rates during perceptual recognition when word frequency and a variety of other psycholinguistic properties were controlled. However, there were no significant effects of word frequency on decision times, VDTs or error/omission rates during the perceptual identification task when AoA and a variety of other psycholinguistic properties were controlled. This suggests that AoA exerted a significant effect on perceptual processing speed and response accuracy during initial recognition processes; whereas word frequency did not. These findings are consistent with the multi-loci perspective and previous studies which have documented significant effects of AoA during tasks which assess perceptual processing. However, further research is required to fully explore the potential loci of AoA and word frequency effects within the cognitive system.

Chapter 4: Picture-Category Verification/Falsification

4.1 Chapter Overview

Chapter 4 expands on the principles and findings reported in Chapter 3 by reporting two semi-factorial picture-category verification/falsification experiments. This task was chosen due to it enabling the programme of research to examine the potential loci of AoA and word frequency effects which arise during perceptual and semantic processing. Experiment 2a investigated the effects of AoA on manual response times[32], error/omission rates[33] and total fixation duration[34] when word frequency, word length, imageability, concreteness, picture-name agreement, category typicality, visual complexity, orthographic neighbourhood size and familiarity were controlled. In contrast, Experiment 2b investigated the effects of word frequency and the response criterion on manual response times, error/omission rates and total fixation durations when AoA, word length, imageability, concreteness, picture-name agreement, category typicality, visual complexity, orthographic neighbourhood size and familiarity were controlled. The experiments also investigated whether trials requiring verification and trials requiring falsification would be differentially affected by AoA and word frequency respectively. Results indicated that AoA and the response criterion influenced perceptual and semantic processing speed but word frequency did not. These findings are subsequently interpreted in the chapter discussion.

[32] Dichotomous keys for yes/compatible and no/incompatible responses.
[33] The total number of errors and omissions produced by each participant and by each item.
[34] The total amount of time participants looked directly at the area containing the critical item while it remained visible on the screen.

4.2 Introduction to Experiments 2a and 2b

As discussed in the previous chapters, research has demonstrated that the age at which stimuli are learnt and the frequency at which it is encountered significantly influences processing speed and accuracy (Bonin, Barry, Méot, & Chalard, 2004; Johnston & Barry, 2006; Juhasz, 2005). These AoA and word frequency effects have been extensively documented across a wide variety of experimental paradigms, stimuli sets and samples (Johnston & Barry, 2006; Juhasz, 2005). However, this chapter focuses on presenting an adaptation of the picture-category verification/falsification experimental paradigm. These adaptations include the use of rigorously controlled semi-factorial stimuli sets, time-sensitive measures of perceptual processing and reliable analytical techniques.

As identified in Chapter 2, Section 2.2.3, picture-category verification/falsification is an appropriate methodological paradigm due to it enabling researchers to identify AoA and word frequency effects during predominantly perceptual and semantic levels of processing (Barry, Morrison, & Ellis, 1997; Bonin, Chalard, Méot, & Fayol, 2002; Chalard & Bonin, 2006; Holmes, Fitch & Ellis, 2006; Morrison, Hirsh, Chappell, & Ellis, 2002; Stadthagen-González, Damian, Pérez, Bowers, & Martin, 2009; Nazir, Decoppet, & Aghababian, 2003). Furthermore, this experimental paradigm is also consistent with multi-loci principles due to requiring the use and synthesis of a wide variety of higher-order processes which develop gradually through the processes of maturation and interleaved learning (Ellis & Lambon Ralph, 2000). However, Chapter 2, Section 2.2.3 also identified that while this is a useful experimental paradigm, it has produced mixed results due to methodological inconsistencies and limitations which are resolved by the studies reported in this chapter.

For example, consistent with Holmes and Ellis (2006), trials requiring verification were analysed separately from trials requiring falsification in the following experiments. This was because the failure to do so appeared to mask the effects of AoA in a previous study conducted by Morrison, Ellis and Quinlan (1992). Indeed, yes/verification and no/falsification draw on different cognitive processes, resources and timescales (Roelofs, 2007). For example, falsification is more cognitively taxing than verification because participants must identify and comprehend the category they have been presented with and then apply logic and memory to identify that this category is inconsistent with the picture presented and identify what the correct category would be (Lewis, 2006; Meyer, Roelofs, & Levelt, 2003). This makes falsification more difficult and time consuming than verification (Brysbaert, van Wijnendaele & de Deyne, 2000; Chalard & Bonin, 2006; Lewis, 2006; Meyer, Roelofs, & Levelt, 2003; Rayner, Chace, Slattery, & Ashby, 2006; Roelofs, 2007). Therefore, results can be confounded when data from trials requiring verification and data from trials requiring falsification are not analysed separately, unless both of these data sets are equally affected by the independent variables.

Secondly, the study conducted by Morrison, Ellis and Quinlan (1992) also employed multiple regression with an insufficient number of predictor variables, post hoc control of confounding variables and a small stimuli set. These issues significantly reduced statistical power and increased the likelihood of Type II error. In contrast, the experiments reported in this chapter employed semi-factorial stimuli sets in which the confounding variables were controlled during experimental design rather than during the analysis. This produced data meeting the requirements of parametric tests and enabled the researcher to analyse the data using more powerful statistical tests than multiple regression. This adaptation addressed the limitations of the previous studies and the criticisms presented by Zevin and Seidenberg (2002) and Lewis (2006) regarding the use of multiple regression in AoA research.

Furthermore, it was also noted in Chapter 2, Section 2.2.3 that previous studies using picture-category verification/falsification have often controlled for the effects of word frequency but have not subsequently investigated the effects of this variable during picture-category verification/falsification (e.g. Holmes & Ellis, 2006). However, proponents of the multi-loci perspective have argued that AoA exerts its strongest influence when the effects of word frequency are minimal (Ellis & Lambon Ralph, 2000). This assumption is of fundamental importance to this thesis which aims to identify the effects, loci and nature of both AoA and word frequency effects. Therefore, the current programme of research expands this approach to also investigate the effects of AoA and word frequency during semi-factorial picture-category verification/falsification experiments. If the assumption of the multi-loci perspective is valid, AoA should exert a strong, independent effect even if word frequency does not.

Another notable limitation of previous AoA research using picture-category verification/falsification is that it is yet to employ more time-sensitive measures of perceptual processing. This has hindered the ability of researchers to identify potential perceptual loci of AoA and word frequency using this experimental paradigm. Indeed, while manual responses provide useful insights into overall processing speed, direct time-sensitive measures can indicate automatic processes which are not confounded by the inevitable delay between perception, identification, comprehension and motor coordination (Rayner, 1998; Juhasz & Rayner, 2003; Roelofs, 2007). Therefore, in addition to recording response times and error/omission rates, the experiments reported in this chapter also incorporated eye-tracking to obtain time-sensitive measures of processing speed.

Indeed, it is notable that research in other areas of psycholinguistics has already documented that the processing of pictorial and textual stimuli can elicit significantly different patterns of gaze (Underwood, Jebbett, & Roberts, 2004) and that fixations on pictures do appear to accurately reflect active cognitive processing (Yee & Sedivy, 2006). However, AoA was not the subject of these investigations and consequently it may have confounded these findings. In contrast, eye-tracking has been used to detect effects of AoA and word frequency during word recognition and sentence reading (Juhasz & Rayner, 2003). This demonstrates that eye-tracking can provide useful insights into the processing of pictorial stimuli and the loci of AoA and word frequency effects. Therefore, the picture-category verification/falsification experiments reported in this chapter investigated the effects of AoA, word frequency and the response criterion on manual response times, error/omission rates and total fixation duration. This experimental paradigm was chosen due to it enabling the researcher to explore the potential loci of AoA and word frequency during perceptual and semantic processing. Indeed, this experimental task does not require lexical access, lexical retrieval or articulation.

4.2.1 Hypotheses for Experiment 2a

Several hypotheses were formulated for Experiment 2a based on the insights provided by previous research and the multi-loci perspective;

- Earlier acquired items will elicit significantly faster manual responses and shorter total fixation durations than later acquired items.
- Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items.
- Trials requiring verification will produce significantly faster manual response and shorter total fixation durations times than trials requiring falsification.
- Trials requiring verification will produce significantly fewer errors/omissions than trials requiring falsification.
- Trials requiring falsification will be more susceptible to AoA effects than trials requiring verification.

4.2.2 Hypotheses for Experiment 2b

Several hypotheses were formulated for Experiment 2b based on the insights provided by previous research and the multi-loci perspective;

- High frequency items will elicit significantly faster manual response times and shorter total fixation durations than low frequency items.

- High frequency items will elicit significantly fewer errors/omissions than low frequency items.
- Trials requiring verification will produce significantly faster manual response times and shorter total fixation durations than trials requiring falsification.
- Trials requiring verification will produce significantly fewer errors/omissions than trials requiring falsification.
- Trials requiring falsification will be more susceptible to word frequency effects than those requiring verification.

4.3 Methodology for Experiment 2a

4.3.1 Design

Experiment 2a utilised a 2 (AoA: early acquired vs. late acquired) x 2 (response criteria: verification vs. falsification) repeated measures design. Therefore, the independent variables were AoA and the response criterion. The first dependent variable was manual response times (ms) as measured by a dichotomous key press. This was operationalised as the difference between the time at which the critical item was presented on the screen and the point at which the participant pressed the key. The second dependent variable was error/omission rate as operationalised as the total number of times the participants provided an incorrect answer, failed to produce a response while the critical item remained on the screen or produced a response which was beyond two standard deviations from the mean. The final dependent variable was the total fixation duration (ms) on each of the critical stimuli. This was operationalised as the total amount of time participants spent looking directly at the critical item while it remained on the screen regardless of the number of times participants shifted their gaze during the trial.

4.3.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 2a, participants consisted of 22 (5 males and 17 females) students and staff from the University of Worcester. Participants ranged from 19 to 42 years of age with a mean age of 22.57 (5.84).

4.3.3 Materials

The materials and AoA stimuli sets for Experiment 2a were identical to those discussed in Chapter 2, Section 2.4.3.1.

4.3.4 Procedure

The calibration of the eye-tracking equipment was described in Chapter 2, Section 2.4.5. After the calibration was complete, participants were instructed to limit their bodily movement throughout the experiment before pressing the spacebar to proceed to the standardised written instructions. When participants understood these instructions they were instructed to press the space bar to complete 6 practice trials. The 68 critical trials followed automatically. For each trial participants viewed a fixation cross in the centre of the screen for 2000ms. The target item and category label were presented simultaneously for 1500ms with the target item in the bottom right of the screen and the category label in the top left of the screen. This approach was adopted to ensure no unintentional priming could occur between the presentations of individual items and to obtain response times which reflected active online processing. Participants were required to indicate whether the category and picture were compatible or incompatible while the items remained on the screen using a dichotomous key press. For example, participants pressed Z on the keyboard if the category and the picture were compatible. In contrast, participants pressed M on the keyboard if the category and the picture were incompatible. Each practice trial was followed by immediate feedback concerning whether the response was correct and the percentage of correct and incorrect responses. However, feedback was not provided on critical trials. An inter-trial interval of 1000ms followed the feedback on practice trials and the target item on critical trials. The order of critical trials was randomised to reduce order, practice or boredom effects. While there was an equal number of trials requiring verification and falsification the response criteria were counterbalanced to reduce the possibility of the response criteria confounding results. Hence, half of the participants verified a picture-category while the remaining half of the participants falsified the same picture-category. After completing the experiments participants were provided with a verbal and standardised written debriefing. Screenshots of the calibration grid, an example critical trial and the debriefing are presented in Figure 4.1. A trial consisted of the third, fourth and fifth screenshot.

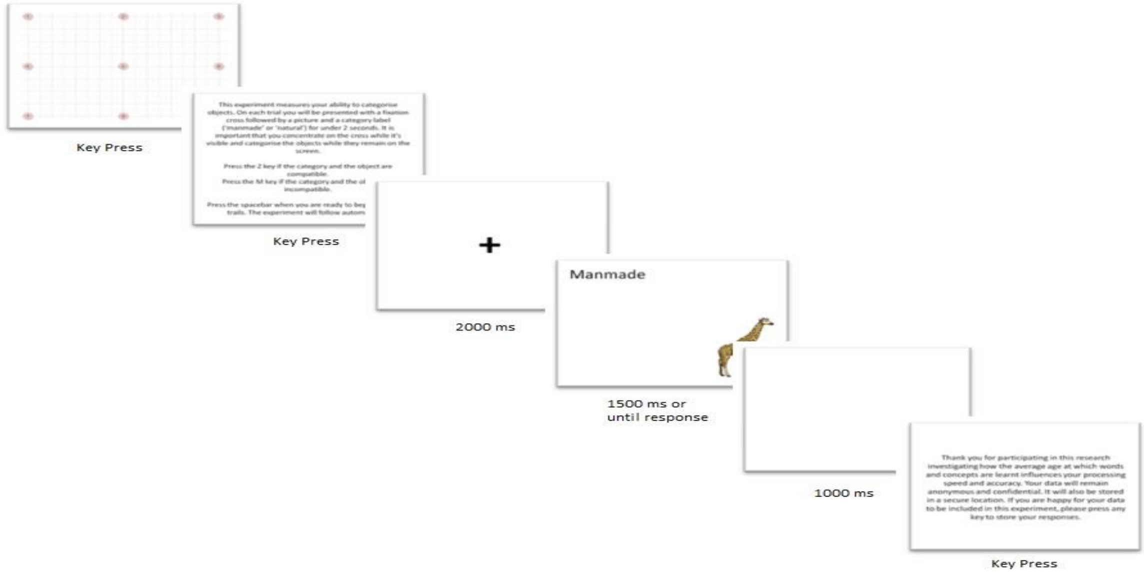

Figure 4.1 The procedure for picture-category verification/falsification tasks

4.4 Results for Experiment 2a

4.4.1 Data Preparation

Data preparation procedures were discussed in Chapter 2, Section 2.5.

4.4.2 Analysis of Response Times

Table 4.1 presents the descriptive statistics for the mean manual response times (ms) and error/omission rates produced during picture-category verification/falsification by-subject and by-item. This suggested that manual response times were faster when participants' processed earlier acquired items (M_1 = 986.58, *SD* = 67.05; M_2 = 979.93, *SD* = 51.06) compared to when they processed later acquired items (M_1 = 1065.89, *SD* = 74.35; M_2 = 1058.24, *SD* = 63.45). It also suggested that manual response times were faster for trials which required verification than for trials which required falsification for both earlier acquired (M_1 = 949.13, *SD* = 86.47; M_2 = 956.90, *SD* = 77.28 vs. M_1 = 1030.29, *SD* = 88.94; M_2 = 1008.65, *SD* = 73.27) and later acquired (M_1 = 1027.34, *SD* = 81.16; M_2 = 1034.43, *SD* = 99.82 vs. M_1 = 1090.66, *SD* = 93.15; M_2 = 1084.32, *SD* = 63.72) stimuli. These descriptive statistics imply that earlier acquired items were processed faster than later acquired items and that verification was a faster cognitive process than falsification.

Table 4.1 Average response times and error/omission rates for Experiment 2a

Measure	Means (SD)	Error Rate (SD)
Early acquired average		
By-Item	979.93 (51.06)	9.54 (3.13)
By-Subject	986.58 (67.05)	14.27 (6.64)
Late acquired average		
By-Item	1058.24 (63.45)	8.12 (3.22)
By-Subject	1065.89 (74.35)	12.55 (6.02)
Early acquired verification		
By-Item	956.90 (77.28)	4.38 (2.24)
By-Subject	949.13 (86.47)	6.55 (2.97)
Early acquired falsification		
By-Item	1008.65 (73.27)	4.85 (1.89)
By-Subject	1030.29 (88.94)	7.73 (4.62)
Late acquired verification		
By-Item	1034.43 (99.82)	3.71 (1.75)
By-Subject	1027.34 (81.16)	5.73 (3.47)
Late acquired falsification		
By-Item	1084.32 (63.72)	4.41 (2.08)
By-Subject	1090.66 (93.15)	6.82 (4.40)

Consequently, manual response times were analysed by-subject and by-item using separate 2 (AoA: early vs. late) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. This revealed that there was a significant main effect of AoA on manual response times in both the by-subject and by-item analyses which accounted for 54% and 50% of the variance respectively, F_1 (1, 21) = 24.965, $p < .001$, partial $\eta^2 = .543$; F_2 (1, 33) = 32.709, $p < .001$, partial $\eta^2 = .498$. There was also a significant main effect of the response criteria on manual response times in the by-subject and by-item analyses which accounted for 57% and 30% of the variance respectively, F_1 (1, 21) = 27.417, $p < .001$, partial $\eta^2 = .567$; F_2 (1, 33) = 14.443, $p < .001$, partial $\eta^2 = .304$. However, the interaction between AoA and the response criteria was not statistically significant by-subject or by-item, F_1 (1, 21) = .419, $p > .05$, partial $\eta^2 = .020$; F_2 (1, 33) = .004, $p > 0.05$, partial $\eta^2 = .001$. Therefore, as illustrated in Table 4.1 manual response times were significantly faster when participants processed earlier acquired items compared to when they processed later acquired items. Manual response times were also significantly faster for verification than for falsification, although there was no significant interaction between AoA and the response criteria during picture-category verification. This implies that there is a locus of AoA at the perceptual-semantic level of processing.

4.4.3 Analysis of Error/Omission Rates

Table 4.1 also demonstrated that the error/omission rates produced during a picture-category verification task were similar across stimuli and condition. Indeed, the error/omission rates produced in response to earlier acquired items (M_1 = 14.27, SD = 6.64; M_2 = 9.54, SD = 3.13) were similar to those produced in response to later acquired items (M_1 = 12.55, SD = 6.02; M_2 = 8.12, SD = 3.22). However, error/omission rates were consistently lower for verification compared to falsification for both earlier acquired (M_1 = 6.55, *SD* = 2.97; M_2 = 4.38, *SD* = 2.24 vs. M_1 = 7.73, *SD* = 4.62; M_2 = 4.85, *SD* = 1.89) and later acquired (M_1 = 5.73, *SD* = 3.47; M_2 = 3.71, *SD* = 1.75 vs. M_1 = 6.82, *SD* = 4.40; M_2 = 4.41, *SD* = 2.08) stimuli. These descriptive statistics suggest that AoA may not have exerted an effect on the error/omission rates during the picture-category verification/falsification task. However, the response criteria may have exerted a significant effect on the error/omission rates.

Error/omission rates were analysed by-subject and by-item using separate 2 (AoA: early vs. late) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. AoA did not have a significant effect by-subject or by-item, F_1 (1, 21) = 1.435, $p > .05$, partial $\eta^2 = .064$; F_2 (1, 33) = 2.911, $p > .05$, partial $\eta^2 = .081$. The main effect of the response criteria was not significant by-subject but was significant by-item and accounted for 13% of the variance, F_1 (1, 21) = 2.923, $p > .05$, partial $\eta^2 = .122$; F_2 (1, 33) = 4.900, $p < .05$, partial $\eta^2 = .129$. Furthermore, the interaction between AoA and the response criteria was not significant by-subject or by-item, F_1 (1, 21) = .004, $p > .05$, partial $\eta^2 < .001$; F_2 (1, 33) = .134, $p > .05$, partial $\eta^2 = .004$. Therefore, neither AoA nor the response criteria exerted consistent, significant main effects on error/omission rates in the by-item analysis although verification was slightly less prone to error in the by-item analyses.

4.4.4 Analysis of Total Fixation Durations

Table 4.2 presents mean total fixation durations (ms) on earlier and later acquired stimuli during picture-category verification by-subject and by-item. This table suggests that participants fixated on later acquired items (M_1 = 511.83, *SD* = 217.55; M_2 = 526.27, *SD* = 86.99) for more time than they fixated on earlier acquired (M_1 = 400.98, *SD* = 123.91; M_2 = 391.03, *SD* = 70.75) items. It also suggests that that trials which required verification elicited shorter total fixation durations than that trials which required falsification for both earlier acquired (M_1 = 374.79, *SD* = 110.16; M_2 = 365.65, *SD* = 92.73 vs. M_1 = 433.59, *SD* = 166.72; M_2 = 415.15, *SD* = 100.41) and later acquired (M_1 = 497.28, *SD* = 208.47; M_2 = 506.95, *SD* = 107.43 vs. M_1 = 538.04, *SD* = 237.77; M_2 = 538.76, *SD* = 120.00) items. These descriptive statistics imply that AoA and the response criterion exerted influences on total fixation durations during picture-category verification with earlier acquired items and verification requiring less visual processing time. Indeed, the shorter total fixation times suggest that earlier acquired items and trials requiring verification required less effortful processing than later acquired items and trials requiring falsification.

Table 4.2 Average total fixation durations for Experiment 2a

Measure	By-Item Mean (SD)	By-Subject Mean (SD
Early acquired average	391.03 (70.75)	400.98 (123.91)
Late acquired average	526.27 (86.99)	511.83 (217.55)
Early acquired verification	365.65 (92.73)	374.79 (110.16)
Late acquired verification	506.95 (107.43)	497.28 (208.47)
Early acquired falsification	415.15 (100.41)	433.59 (166.72)
Late acquired falsification	538.76 (120.00)	538.04 (237.77)

Subsequently, total fixation durations were analysed by-subject and by-item using separate 2 (AoA: early vs. late) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. This revealed that there was a significant main effect of AoA on total fixation durations by-subject and by-item which accounted for 41% and 58% of the variance respectively, F_1 (1, 19) = 12.990, $p < .01$, partial $\eta^2 = .406$; F_2 (1, 33) = 45.952, $p < .001$, partial $\eta^2 = .582$. In regards to the response criteria, there was a significant main effect on total fixation duration in both the by-subject and by-item analyses which accounted for 19% and 17% of the variance respectively, F_1 (1, 19) = 4.480, $p < .05$, partial $\eta^2 = .191$; F_2 (1, 33) = 6.930, $p < .05$, partial $\eta^2 = .174$. However, there was no significant interaction between AoA and the response criteria by-subject or by-item, F_1 (1, 19) = 2.200, $p > .05$, partial $\eta^2 = .104$; F_2 (1, 33) = .214, $p > .05$, partial $\eta^2 = .006$. Therefore, both AoA and the response criteria exerted significant main effects on total fixation duration during the picture-category verification/falsification task; earlier acquired stimuli were processed significantly faster than later acquired items and verification eliciting significantly faster responses than falsification independent of AoA. This suggests that AoA exerts a significant effect on perceptual-semantic processing speed during picture-category verification/falsification. However, despite the effect on response times, AoA did not exert a significant effect on response accuracy. The implications of these findings for the hypotheses are discussed in the chapter discussion. Experiment 2b subsequently investigated whether word frequency exerted similar effects to those produced by AoA during this experimental task.

4.5 Methodology for Experiment 2b

4.5.1 Design

Experiment 2b utilised a 2 (frequency: low frequency vs. high frequency) x 2 (response criteria: verification vs. falsification) repeated measures design. Therefore, the independent variables were word frequency and the response criterion. The dependent variables were identical to those of Experiment 2a.

4.5.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 1b, participants consisted of 22 (3 males and 19 females) students and staff from the University of Worcester. Participants ranged from 19 to 45 years of age with a mean age of 24.86 (6.59).

4.5.3 Materials

With the exception of the stimuli all materials were identical to that used for Experiment 2a. The word frequency stimuli sets were described in Chapter 2, Section 2.4.3.2.

4.5.4 Procedure

The procedure was identical to that used in Experiment 2a.

4.6 Results for Experiment 2b

4.6.1 Data Preparation

Data preparation procedures were discussed in Chapter 2, Section 2.5.

4.6.2 Analysis of Response Times

Table 4.3 presents the descriptive statistics for response times and error/omission rates by-subject and by-item for each condition in Experiment 2b. Contrary to the hypotheses, this suggested that the average manual response times produced by participants were similar for lower frequency (M_1 = 1073.35, *SD* = 100.49; M_2 = 1067.31, *SD* = 56.94) and high frequency (M_1 = 1073.56, *SD* = 87.98; M_2 = 1059.88, *SD* = 60.60) items. However, it also suggests that manual response times were quicker for trials which required verification than for trials which required falsification for both low frequency (M_1 = 1028.03, *SD* = 105.50; M_2 = 1035.95, *SD* = 94.26 vs. M_1 = 1117.54, *SD* = 111.49; M_2 = 1111.00, *SD* = 58.36) and high frequency M_1 = 1059.95, *SD* = 112.57; M_2 = 1041.54, *SD* = 86.61 vs. M_1 = 1093.54, *SD* = 90.26; M_2 = 1088.32, *SD* = 82.46) items. These descriptive statistics imply that word frequency did not influence manual response times during the picture-category verification/falsification task. However, trials requiring verification produced faster average manual response times than trials requiring falsification.

Table 4.3 Response times and error/omission rates for Experiment 2b

Measure	Means (SD)	Error Rate (SD)
Low frequency average		
By-Item	1067.31 (56.94)	6.12 (2.65)
By-Subject	1073.35 (100.49)	9.36 (4.89)
High frequency average		
By-Item	1059.88 (60.60)	6.74 (2.37)
By-Subject	1073.56 (87.98)	10.41 (5.44)
Low frequency verification		
By-Item	1035.95 (94.26)	3.06 (2.00)
By-Subject	1028.03 (105.50)	4.27 (2.93)
Low frequency falsification		
By-Item	1111.00 (58.36)	3.06 (1.59)
By-Subject	1117.54 (111.49)	5.09 (2.64)
High frequency verification		
By-Item	1041.54 (86.61)	3.12 (1.78)
By-Subject	1059.95 (112.57)	4.82 (2.86)
High frequency falsification		
By-Item	1088.32 (82.46)	3.62 (1.97)
By-Subject	1093.54 (90.26)	5.59 (2.86)

Manual response times were analysed by-subject and by-item using separate 2 (frequency: low frequency vs. high frequency) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. The main effect of word frequency on manual response times was not significant in either the by-subject or by-item analyses, F_1 (1, 21) = .094, $p > .05$, partial $\eta^2 = .004$; F_2 (1, 33) = .305, $p > .05$, partial $\eta^2 = .009$. Therefore, word frequency did not exert a significant effect on manual response times during picture-category verification/falsification. However, there was a significant main effect of the response criteria on manual response times in the by-subject and by-item analyses which accounted for 39% and 35% of the variance respectively, F_1 (1, 21) = 13.390, $p < .001$, partial $\eta^2 = .389$; F_2 (1, 33) = 17.532, $p < .001$, partial $\eta^2 = .347$.

While the interaction between word frequency and the response criteria was significant in the by-subject analyses and accounted for 27% of the variance it was not significant in the by-item analyses, F_1 (1, 21) = 7.605, $p < .05$, partial $\eta^2 = .266$; F_2 (1, 33) = 1.149, $p > .05$, partial $\eta^2 = .034$. Post-hoc tests with an adjusted alpha value of 0.01 revealed that low frequency verification produced significantly faster manual response times than high frequency falsification by-subject but not by-item, t_1 (21) = -2.899, $p < .01$; t_2 (33) = -2.086, $p > .01$. Furthermore, it also revealed that high frequency verification produced significantly faster manual responses than low frequency falsification by-subject and by-item, t_1 (21) = +2.920, $p < .01$; t_2 (33) = +4.217, $p < .001$. This suggests that trials requiring falsification may have exaggerated the difference between the low and high frequency stimuli. Therefore, word frequency exerted little influence on manual response times during picture-category verification/falsification, although manual responses were significantly faster for verification than for falsification.

4.6.3 Analysis of Error/Omission Rates

Table 4.3 demonstrated that error/omission rates were similar across stimuli and condition. Indeed, the differences between the average number of errors produced in response to low frequency items (M_1 = 9.36, SD = 4.89; M_2 = 6.12, SD = 2.65) was similar to that produced in response to high frequency items (M_1 = 10.41, SD = 5.44; M_2 = 6.74, SD = 2.37). However, error/omission rates were consistently lower for verification compared to falsification for both low frequency (M_1 = 4.27, SD = 2.93; M_2 = 3.06, SD = 2.00 vs. M_1 = 5.09, SD = 2.64; M_2 = 3.06, SD = 1.59) and high frequency (M_1 = 4.82, SD = 2.86; M_2 = 3.12, SD = 1.78 vs. M_1 = 5.59, SD = 2.86; M_2 = 3.62, SD = 1.97) stimuli. These descriptive statistics implied that the response criterion influenced error/omission rates but that word frequency did not.

Consequently, error/omission rates were also analysed by-subject and by-item using separate 2 (frequency: low vs. high) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. This revealed that word frequency did not exert a significant main effect on error/omission rates by-subject or by-item, F_1 (1, 21) = 1.981, $p > .05$, partial $\eta^2 = .086$; F_2 (1, 33) = .918, $p > .05$, partial $\eta^2 = .027$. Therefore, word frequency did not exert an effect on response accuracy during picture-category verification/falsification. Furthermore, while the main effect of the response criteria on error/omission rates was significant by-subject and accounted for 20% of the variance it was not significant by-item F_1 (1, 21) = 5.332, $p < .05$, partial $\eta^2 = .202$; F_2 (1, 33) = .567, $p > .05$, partial $\eta^2 = .017$. Finally, there was no significant interaction between word frequency and the response criteria in the by-subject or by-item analyses F_1 (1, 21) = .005, $p > .05$, partial $\eta^2 = .001$; F_2 (1, 33) = .628, $p > .05$, partial $\eta^2 = .019$. This indicates that low frequency items were no more prone to error than high frequency items.

4.6.4 Analysis of Total Fixation Durations

Table 4.4 presents mean total fixation durations (ms) for low and high frequency stimuli during picture-category verification. This suggested that there was little variation in total fixation duration between conditions and implies that there was no effect of word frequency or the response criteria on total fixation duration. Indeed, the average total fixation duration for low frequency items (M_1 = 362.06, *SD* = 212.36; M_2 = 393.19, *SD* = 56.81) was similar to that for high frequency (M_1 = 347.15, *SD* = 185.12; M_2 = 365.30, *SD* = 52.39) items. The differences between mean total fixation duration verification and falsification were also similar for both low frequency (M_1 = 359.77, *SD* = 216.42; M_2 = 396.56, *SD* = 103.38 vs. M_1 = 363.58, *SD* = 216.01; M_2 = 389.32, *SD* = 108.77) and high frequency (M_1 = 340.98, *SD* = 182.67; M_2 = 370.97, *SD* = 182.67 vs. M_1 = 351.18, *SD* = 189.79; M_2 = 370.09, *SD* = 91.65) items. These descriptive statistics implied that neither word frequency nor the response criterion exerted an influence on total fixation durations during picture-category verification.

Table 4.4 Average total fixation durations for Experiment 2b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency average	393.19 (56.81)	362.06 (212.36)
High frequency average	365.30 (52.39)	347.15 (185.12)
Low frequency verification	396.56 (103.38)	359.77 (216.42)
High frequency verification	370.97 (75.00)	340.98 (182.67)
Low frequency falsification	389.32 (108.77)	363.58 (216.01)
High frequency falsification	370.09 (91.65)	351.18 (189.79)

Total fixation durations were analysed by-subject and by-item using separate 2 (frequency: low vs. high) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. This revealed that the main effect of word frequency on total fixation durations was not significant by-subject or by-item, F_1 (1, 21) = 1.864, $p >$ .05, partial η^2 = .082; F_2 (1, 33) = 3.000, $p >$ .05, partial η^2 = .083, Therefore, word frequency did not have a significant effect on perceptual processing speed during picture-category verification/falsification. Furthermore, the main effect of the response criteria on total fixation duration was not significant by-subject or by-item, F_1 (1, 21) = .449, $p >$ .05, partial η^2 = .021; F_2 (1, 33) = .076, $p >$ .05, partial $\eta^2 <$ .01. Finally, there was no significant interaction between word frequency and the response criteria by-subject or by-item, F_1 (1, 21) = .165, $p >$ .05, partial η^2 = .008; F_2 (1, 33) = .020, $p >$ .05, partial η^2 = .020.

Therefore, Experiment 2b indicates that word frequency does not exert a significant effect during a picture-category verification/falsification task when AoA, word length, category typicality, concreteness, familiarity, visual complexity and imageability have been controlled. However, it also implies that the response criterion can interact with word frequency and exasperate the processing disadvantage for low frequency stimuli when a manual response is required.

4.7 Discussion of Results for Experiments 2a-2b

The experiments reported in this chapter investigated the effects of AoA, word frequency and the response criterion on manual response times, total fixation duration and error/omission rates during an adaptation of the picture-category verification/falsification task. Several methodological amendments were implemented to address the limitations of previous research. This included the use of the rigorously controlled, semi-factorial stimuli set discussed in Chapter 2, Section 2.4.3.1. This ensured that confounding variables such as imageability, picture-name agreement, visual complexity, orthographic neighbourhood density, word length and concreteness were controlled during experimental design rather than during the analyses (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Furthermore, to the best of the researchers' knowledge, these experiments were also the first studies to investigate the effects of AoA using picture-category verification/falsification in conjunction with eye-tracking. This measure was incorporated to enable the researcher to identify any perceptual effects which arose during this task. Finally, the responses for verification and falsification were analysed separately to ensure that the response criteria did not confound the results as identified in earlier studies (e.g. Morrison, Ellis & Quinlan, 1992). Therefore, the experimental adaptations employed during these experiments enabled to researcher to work towards meeting the aims and objectives identified in Chapter 1, Section 1.3.1. Indeed, this experimental paradigm facilitated the identification of potential loci at perceptual and semantic levels of processing (Catling & Johnston, 2009; Holmes & Ellis, 2006). The implications of the results from Experiment 2a for the hypotheses are summarised in Table 4.5.

This table demonstrates that AoA did exert a significant main effect during a task requiring perceptual and semantic processing after word frequency, picture-name agreement, category typicality, visual complexity, concreteness, imageability and word length were controlled. Therefore, earlier acquired items were processed significantly faster than later acquired items and this was reflected in both total fixation durations and manual response times. This is consistent with earlier studies which have demonstrated that the effects of AoA were not reducible to the influence of other influential psycholinguistic properties (Brysbaert & Ghyselinck, 2006; Cortese & Khanna, 2007).

This illustrates that AoA remains an influential variable even when stimuli sets are tightly controlled. It also demonstrates that AoA exerts significant effects during perceptual and semantic processing.

Table 4.5 Implications for the hypotheses of Experiment 2a

Hypothesis	Evidence
Earlier acquired items will elicit significantly faster manual responses and shorter total fixation durations than later acquired items.	Supported
Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items.	Not supported
Trials requiring verification will produce significantly faster manual response times and shorter total fixation durations than trials requiring falsification.	Supported
Trials requiring verification will produce significantly fewer errors/omissions than trials requiring falsification.	Partially supported
Trials requiring falsification will be more susceptible to AoA effects than trials requiring verification.	Not supported

It is also notable that the response criterion exerted a significant effect on total fixation durations and manual responses during the picture-category verification/falsification task. Indeed, verification was a consistently faster process than falsification and this was evident in both manual (e.g. key press) and automatic (e.g. total fixation duration) responses. However, it is notable that the effect size of AoA on response times and total fixation durations were consistently higher than those of the response criteria with the exception of the by-subject analysis of the manual response time data. This suggests that AoA exerted a more pronounced effect on perceptual and semantic processing than the response criterion exerted. These findings only partially support Holmes and Ellis (2006), who observed AoA effects in picture-category verification but not during picture-category falsification. However, the current research also identified that AoA effects remained significant after category-typicality and a number of other psycholinguistic properties were controlled. This implies that the stimuli set used in the current research may have been more tightly controlled than the materials used by Holmes and Ellis (2006). Therefore, the differences between the findings reported in this chapter and those reported by Holmes and Ellis (2006) may be explained by methodological differences.

However, there was no effect of AoA on response accuracy and the response criteria only exerted a significant effect on error/omission rates in the by-subject analyses. This implies that AoA exerted more influence on response times than on response accuracy (Bonin, Fayol, & Chalard, 2001; Johnston & Barry, 2006). It also implies that participants found falsification to be a more difficult decision process than verification; consistent with arguments that falsification is a more cognitive taxing process than verification (Meyer, Roelofs, & Levelt, 2003; Roelofs, 2009).

Table 4.6 demonstrates how the findings from Experiment 2b relate to the hypotheses. The main finding from this experiment was that word frequency did not exert a significant effect on manual response times, total fixation durations or error/omission rates when AoA, word length, familiarity, concreteness, picture-name agreement, visual complexity and category typicality were controlled. Furthermore, while verification produced significantly faster manual response times than falsification, the response criterion did not influence total fixation durations and only influenced error/omission rates in the by-subject analysis. This adds further support to the argument that verification is a less cognitively taxing process than falsification (Brysbaert, van Wijnendaele & de Deyne, 2000; Chalard & Bonin, 2006; Lewis, 2006; Meyer, Roelofs, & Levelt, 2003; Rayner, Chace, Slattery, & Ashby, 2006; Roelofs, 2007). Interpreted in the context of Experiment 2a, these findings are also consistent with the multi-loci principle in which AoA effects can occur independently of word frequency effects (Brysbaert & Ghyselinck, 2006; Johnston & Barry, 2006; Ellis & Lambon Ralph, 2000). These findings also present implications concerning the loci of AoA effects and the theories discussed in Chapter 1.

Table 4.6 Implications for the hypotheses of Experiment 2b

Hypothesis	Evidence
High frequency items would elicit significantly faster manual response times and shorter total fixation durations than low frequency items.	Not supported
High frequency items would elicit significantly fewer errors/omission than low frequency items.	Not supported
Trials requiring verification would produce significantly faster manual response times and shorter total fixation durations than trials requiring falsification.	Supported
Trials requiring verification would produce significantly fewer errors/omissions than trials requiring falsification.	Partially supported
Trials requiring falsification would be more susceptible to word frequency effects than trials requiring verification.	Partially supported

For example, while picture-category verification/falsification is a predominantly semantic task which relies on object recognition and categorisation, the effects of AoA on total fixation duration suggests that there is an earlier locus of AoA effects during perceptual processing or between perceptual and semantic processing (Catling & Johnston, 2009; Juhasz, 2005; Rayner, 1998). This proposition is consistent with previous studies which have documented significant AoA effects on perceptual processing speed during reading and object recognition (Johnston & Barry, 2006; Juhasz, 2005; Juhasz & Rayner, 2006). Indeed, Yee and Sedivy (2006) identified that eye-movements reflect both perceptual and semantic processing. It is also notable that Dent, Catling and Johnston (2007) examined visual duration thresholds and identified that AoA appeared to influence visual object recognition but not pre-recognition processes. This supports the proposition that there is a perceptual basis for AoA effects.

When interpreted in context, the findings from Experiments 2a and 2b imply that AoA, rather than word frequency, influenced processing speed during picture-category verification/falsification. These findings are consistent with evidence suggesting that AoA effects can occur independently of word frequency effects (Brysbaert & Ghyselinck, 2006). Indeed, while a full consideration of frequency-independent and frequency-related AoA effects was presented in Chapter 1, Section 1.2, it is notable that frequency-independent AoA effects are usually observed in tasks which do not require direct lexical access (Brysbaert & Ghyselinck, 2006; Cuetos, Alvarez, Gonzalez-Nosti, Méot & Bonin, 2006). The experiments reported in this chapter support this proposition. This suggests that it would be advantageous to the aims and objectives of this thesis to conduct further research incorporating tasks which explicitly require this level of processing. Indeed, this would facilitate the identification of AoA and word frequency effects during indirect lexical access.

Therefore, Experiments 3a and 3b investigated the effects of AoA, word frequency and the response criterion during a picture-name verification/falsification task. This is a logical step in regards to gradually increasing processing demands because in addition to perceptual and semantic processing, picture-name verification/falsification also relies on indirect lexical access and lexical retrieval for successful word and picture recognition. For example, participants must identify the object in the visual field and determine whether the name presented corresponds to the object based on semantic and lexical information. However, all other procedural and analytical elements remained identical to those used for Experiments 2a and 2b. This was intentional to ensure that it was possible to compare the findings across these studies.

4.8 Chapter Conclusion

Chapter 4 provided an overview of two picture-category verification/falsification experiments which investigated the effects of AoA, word frequency and the response criteria on processing speed and accuracy. These experiments built on the findings reported in Chapter 3 by utilising a task which relied on both perceptual and semantic processing. Subsequently, the experiments reported in Chapter 4 revealed that AoA and the response criterion exerted significant main effects on manual response times and total fixation durations during the picture-category verification/falsification task. This suggests that there is at least one locus of AoA at a perceptual and/or semantic level of processing. However, word frequency did not influence manual response times, total fixation durations or error/omission rates during picture-category verification/falsification. Similar to the findings reported in relation to perceptual identification (Chapter 3), this suggests that AoA effects occur independently of word frequency effects during this experimental paradigm. However, picture-category verification/falsification tasks do not require lexical access, which previous research has linked to frequency-related AoA effects (Bonin, Fayol, & Chalard, 2001; Brysbaert & Ghyselinck, 2006; Johnston & Barry, 2006). Indeed, as outlined in Chapter 1 and Chapter 2, it is vital that the research reported in this thesis facilitates the exploration of nature and loci of AoA and word frequency effects throughout the cognitive system. Consequently, Chapter 5 reports two semi-factorial experiments which investigated the effects of AoA, word frequency and the response criterion on manual response times, total fixation durations and error/omission rates during a picture-name verification/falsification task. This experimental design was chosen because it enabled the researcher to identify potential loci of AoA and word frequency effects during perceptual processing, semantic processing, indirect lexical access and indirect lexical retrieval. Chapter 6 and Chapter 7 subsequently extend the investigation to direct lexical retrieval and articulation.

Chapter 5: Picture-Name Verification/Falsification

5.1 Chapter Overview

Chapter 5 extends the principles and findings of Chapter 3 and Chapter 4. Indeed, it presents two semi-factorial, picture-name verification/falsification experiments which were more cognitively taxing than picture-category verification/falsification. This task was chosen due to it enabling the researcher to examine the potential loci of AoA and word frequency effects which arise during perceptual processing, semantic processing and indirect lexical access. Consequently, Experiment 3a investigated the effects of AoA on manual response times, error/omission rates and total fixation duration when word frequency, word length, imageability, concreteness, picture-name agreement, category typicality, visual complexity, orthographic neighbourhood size and familiarity were controlled. In contrast, Experiment 3b investigated the effects of word frequency and the response criterion on manual response times, error/omission rates and total fixation durations when AoA, word length, imageability, concreteness, picture-name agreement, category typicality, visual complexity, orthographic neighbourhood size and familiarity were controlled. The experiments also investigated whether trials requiring verification and trials requiring falsification would be differentially affected by AoA and word frequency respectively. Results suggested that AoA and the response criterion influenced perceptual processing, semantic processing and indirect lexical access. However, word frequency did not exert consistent or significant effects during picture-name verification/falsification. These findings are subsequently interpreted in the chapter discussion.

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5.2. Introduction to Experiments 3a and 3b

Experiments 1a and 1b (Chapter 3) demonstrated that there were significant effects of AoA on decision times, VDTs and error/omission rates during perceptual identification, but there were no significant effects of word frequency. Furthermore, Experiments 2a and 2b (Chapter 4) demonstrated that AoA and the response criterion exerted significant but independent effects on perceptual-semantic processing during a picture-category verification/falsification task. The findings from these experiments provided support for the multi-loci perspective of AoA effects, but contradicted the localist theories (Catling & Johnston, 2009; Ellis, 2012; Holmes & Ellis, 2006; Moore, Smith-Spark & Valentine; 2004). Indeed, neither the PCH or the SH can explain the effects of AoA which were observed during perceptual processing, as measured by total fixation duration and VDTs. Furthermore, these AoA effects were evident despite the control of word frequency, imageability, concreteness, typicality, word length, visual complexity and picture-name agreement. This contradicts claims that AoA effects are merely a by-product of word frequency effects (Zevin & Seidenberg, 2002, 2004). For example, word frequency had very little effect on perceptual or semantic processing when AoA, imageability, concreteness, typicality, word length, visual complexity and picture-name agreement were controlled. These experiments also confirmed that previous research may have provided incomplete interpretations due to not considering the co-occurring, independent effects of the response criteria (Holmes & Ellis, 2006; Lewis, 2006; Roelofs, 2007). However, further research is still required to expand these findings and identify whether AoA and word frequency effects are evident in tasks which also require lexical access (Catling & Johnston, 2009; Ellis & Lambon Ralph, 2000; Stadthagen-Gonzalez, Damian, Pérez, Bowers & Marín, 2009).

Indeed, several researchers have argued that there are at least two loci of AoA effects with one emerging during the earliest stages of cognitive processing and another occurring during the later stages of lexicalisation (Catling & Johnston, 2009; Holmes & Ellis, 2006; Johnston & Barry, 2006; Moore, Smith-Spark & Valentine; 2004). These loci can also be differentially affected by word frequency. For example, while frequency-independent AoA effects are typically detected during tasks which require perceptual and semantic processing; frequency-related AoA effects are usually observed during tasks which require lexical access, retrieval and/or articulation (Bonin, Fayol & Chalard, 2001; Brysbaert & Ghyselinck, 2006; Johnston & Barry, 2006). This has significant ramifications for theories concerning the loci and nature of AoA and word frequency effects. For example, one of the fundamental predictions of the multi-loci perspective is that AoA effects will decline when word frequency exerts a significant effect due to the confounding influence of this variable (Alvarez & Cuetos, 2007; Anderson; 2008; Brysbaert & Cortese, 2011; Brysbaert & Ghyselinck, 2006; Cortese, Khanna & Hacker. 2010; De Deyne & Storms, 2007; Ellis, Holmes & Wright, 2010; Kittredge et al., 2008; Lambon Ralph & Ehsan, 2006). In contrast, the main prediction of the PCH is that the strongest AoA effects will be detected during tasks which require lexical access, retrieval and articulation (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Garlock, Walley, & Metsala, 2001; Moore, Smith-Spark, & Valentine, 2004). Identifying whether AoA and word frequency effects co-occur during a task which requires lexical access may subsequently identify which, if either, of these predictions is valid.

A useful experimental paradigm which can be used to investigate the effects of AoA and word frequency during early lexical processing is the picture-name verification/falsification task (Catling & Johnston, 2006a; Johnston & Barry, 2006; Juhasz, 2005; Moore, Smith-Spark & Valentine; 2004). Like picture-category verification/falsification, this task relies on visual recognition processes and semantic processes to identify stimuli (Johnston & Barry, 2006; Moore, Smith-Spark & Valentine; 2004). However, unlike picture-category verification/falsification, picture-name verification/falsification also requires access to the mental lexicon to retrieve the correct name of the stimuli and compare this to the labels presented on the screen (Bakhtiar & Weekes, 2014; Lambon Ralph & Ehsan, 2006; Yee & Sedivy, 2006). As outlined in Chapter 2, Section 2.2.4, the cognitive process for this task follows the indirect route to lexical access using the semantic properties of the stimuli due to the arbitrary mapping between the visual stimuli and the phonological form of the word. Furthermore, articulation is not required for successful picture-name verification/falsification. This suggests that this is an ideal task to investigate whether there are loci of AoA and word frequency effects during lexical access and retrieval.

To date results from picture-name verification/falsification tasks and similar experimental tasks have been inconclusive. For example, Catling and Johnston (2006a) observed that earlier acquired items were processed significantly faster than later acquired items during a picture-name verification/falsification task. These AoA effects were also significantly stronger than those which were observed during picture-category verification. This suggests that there are at least two loci of AoA effects which occur prior to the later stages of lexicalisation (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Brysbaert, Van Wijnendaele, & De Deyne, 2000; Dent, Catling, & Johnston, 2007; Ghyselinck, Custers, & Brysbaert, 2004; Ghyselinck, Lewis, & Brysbaert, 2004; Moore, Smith-Spark, & Valentine, 2004; Steyvers & Tenenbaum, 2005). Indeed, Catling and Johnston (2009) argued that AoA effects may gradually increase in strength as task complexity and processing demands increase. However, the effects of word frequency and the response criteria were not examined during this experiment despite research indicating that these variables have a significant influence over both response times and response accuracy (Johnston & Barry, 2006; Juhasz. 2006; Lewis, 2006; Roelofs, 2007). For example, while Holmes and Ellis (2006) observed significant AoA effects during picture-category verification (but not during picture-category falsification), these effects lost statistical significance after typicality was controlled during a subsequent statistical process. This demonstrates that AoA research is susceptible to the confounding influence of other psycholinguistic properties if these factors are not adequately controlled (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Indeed, it is notable that the inability of previous studies to replicate AoA effects in picture-name verification tasks may also be attributed to differences in stimuli set integrity and statistical procedures (Lewis, 2006; Zevin & Seidenberg, 2002). As detailed in Chapter 2 and demonstrated in Chapter 3 and Chapter 4, a semi-factorial design allows researchers to control a wide variety of psycholinguistic properties and detect consistent patterns of results. Therefore, the stimuli which were used in the previous experiments were used in Experiments 3a and 3b.

Further methodological adaptation was also required to improve the reliability and validity of the picture-name verification/falsification paradigm and assess whether there are effects of AoA, the response criteria and word frequency during this task. For example, in the original format of this task a picture was presented independently followed by a name which was either compatible or incompatible with the previously presented picture (Catling & Johnston, 2006a; Chalard & Bonin, 2006; Johnston & Barry, 2006; Moore, Smith-Spark & Valentine; 2004). In the case of presenting a concurrent picture-word pair, this can evoke between-domain priming. Indeed, the previous presentation of the picture can prime the subsequent processing of the word thereby distorting results and producing misleading results during trials requiring verification (Anderson, 2008; Barry, Hirsh, Johnston & Williams, 2001; Barry Johnston & Wood, 2006; Catling & Johnston, 2006b; Lewis, 2006; Lewis, Chadwick & Ellis, 2002). This suggests that data derived from verification and falsification should be analysed separately and it would be more appropriate to present the picture and word simultaneously to remove the possibility of priming (Lewis, 2006; Roelofs, 2007; Underwood, Jebbett & Roberts, 2004). Indeed, sequentially presenting a picture followed by a word in the same location after a brief interval may also be confounded by inhibition of return (IoR). IoR refers to the phenomenon in which an individual is not able to voluntarily move their gaze back to a previously attended area for a short amount of time following the previous fixation (Juhasz & Rayner, 2003, 2006; Rayner, 1998; Rayner, Chace, Slattery & Ashby, 2006; Underwood, Jebbett & Roberts, 2004). This delay in returning gaze to the previously attended location could potentially slow detection of the following stimulus and consequently present a distorted response time.

Therefore, two experiments were conducted to investigate the effects of AoA, word frequency and the response criteria on manual response times, error/omission rates and total fixation durations during an adaptation of the picture-name verification/falsification task. Methodological adaptations included the use of semi-factorial stimuli sets, measurement of total fixation durations, simultaneous presentation of the labels and the pictures and separate analyses of data from trials requiring verification and falsification. This experimental paradigm was chosen due to it enabling the researcher to expand on the findings presented in Chapter 3 and Chapter 4. Indeed, the perceptual identification task investigated whether there were significant effects of AoA and word frequency during initial recognition processes while picture-category verification/falsification investigated if there were significant effects of AoA and word frequency during perceptual and semantic processing. In contrast, picture-name verification/falsification can investigate whether there are significant effects of AoA and word frequency during perceptual processing, semantic processing and indirect lexical access.

5.2.1 Hypotheses for Experiment 3a

Several hypotheses were formulated for Experiment 3a based on the literature and the multi-loci perspective;

- Earlier acquired items will elicit significantly faster manual response times and shorter total fixation durations than later acquired items.
- Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items.
- Trials requiring verification will elicit significantly faster manual response times and shorter total fixation durations than trials requiring falsification.
- Trials requiring verification will elicit significantly fewer errors/omissions than trials requiring falsification.

- Trials requiring falsification will be significantly more susceptible to the effects of AoA than trials requiring verification.

5.2.2 Hypotheses for Experiment 3b

Several hypotheses were also formulated for Experiment 3b based on the literature and the multi-loci perspective;

- High frequency items will elicit significantly faster manual response times and shorter total fixation durations than low frequency items.
- High frequency items will elicit significantly fewer errors/omissions than low frequency items.
- Trials requiring verification will produce significantly faster manual response times and shorter total fixation durations than trials requiring falsification.
- Trials requiring verification will elicit significantly fewer errors/omissions than trials requiring falsification.
- Trials that require falsification will be significantly more susceptible to the influence of word frequency than trials requiring verification.

5.3 Methodology for Experiment 3a

5.3.1 Design

Experiment 3a utilised a 2 (AoA: early acquired vs. late acquired) x 2 (response criteria: verification vs. falsification) repeated measures design. Therefore, the independent variables were AoA and the response criterion. The first dependent variable was manual response times (ms) as measured by a dichotomous key press. This was operationalised as the difference between the time at which the critical item was presented on the screen and the point at which the participant pressed the key. The second dependent variable was error/omission rate as operationalised as the total number of times the participants provided an incorrect answer, failed to produce a response while the critical item remained on the screen or produced a response which was beyond two standard deviations from the mean. The final dependent variable was the total fixation duration (ms) on each of the critical stimuli. This was operationalised as the total amount of time participants spent looking directly at the critical item while it remained on the screen regardless of the number of times participants shifted their gaze during the trial.

5.3.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 3a, participants consisted of 22 female students and staff from the University of Worcester. Participants ranged from 18 to 49 years of age with a mean age of 25.23 (7.79).

5.3.3 Materials

The materials and AoA stimuli sets for Experiment 3a were identical to those discussed in Chapter 2, Section 2.4.3.1. However, when an item was paired with an incompatible name, this name was drawn from the same stimuli set. This meant that incompatible items were always paired with a word with similar properties to the correct word.

5.3.4 Procedure

The calibration of the eye-tracking equipment was described in Chapter 2, Section 2.4.5. After the calibration was complete, participants were instructed to limit their bodily movement throughout the experiment before pressing the spacebar to proceed to the standardised written instructions. When participants understood these instructions they were instructed to press the space bar to complete 6 practice trials. The 68 critical trials followed automatically. For each trial participants viewed a fixation cross in the centre of the screen for 2000ms. The target item and object name were presented simultaneously for 1500ms with the target item in the bottom right of the screen and the object name in the top left of the screen. This approach was adopted to ensure no unintentional priming could occur between the presentations of individual items and to obtain response times which accurately reflected active online processing. Participants were required to indicate whether the name and the picture were compatible or incompatible while the items remained on the screen using a dichotomous key press. For example, participants pressed Z on the keyboard if the name and the picture were compatible. In contrast, participants pressed M on the keyboard if the name and the picture were incompatible. Each practice trial was followed by immediate feedback concerning whether the response was correct and the percentage of correct and incorrect responses. However, feedback was not provided on critical trials. An inter-trial interval of 2000ms followed the feedback on practice trials and the target item on critical trials. The order of critical trials was randomised to reduce order, practice or boredom effects. While there were an equal number of trials requiring verification and falsification the response criteria were counterbalanced to reduce the possibility of the response criteria confounding results. Hence, half of the participants verified a picture-name pair while the remaining half of the participants falsified the same picture-name pair. After completing the experiments participants were provided with a verbal and standardised written debriefing. Figure 5.1 presents screenshots of the calibration grid, critical trials and debriefing for the picture-name verification experiment. A trial consisted of the third, fourth and fifth screen shot.

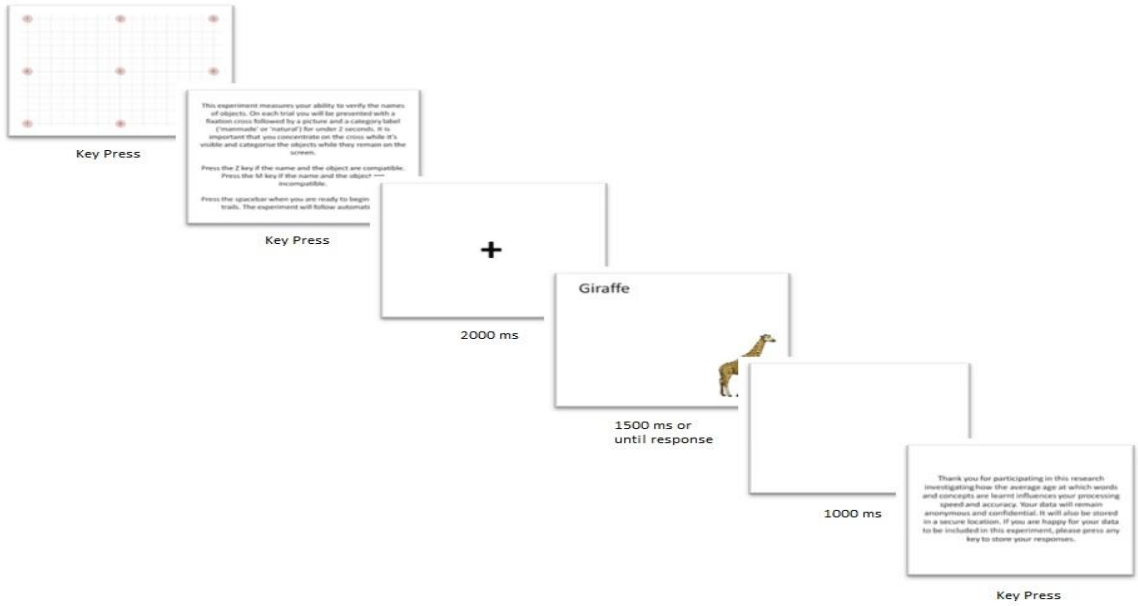

Figure 5.1 The procedure for picture-name verification/falsification tasks

5.4 Results for Experiment 3a

5.4.1 Data Preparation

Data preparation processes were discussed in Chapter 2, Section 2.5.

5.4.2 Analysis of Response Times

Table 5.1 presents the descriptive statistics for the picture-name verification/falsification task in which AoA was manipulated. This suggests that average manual response times were faster when participants processed earlier acquired items (M_1 = 844.58, *SD* = 64.61; M_2 = 838.58, *SD* = 40.17) compared to when they processed later acquired items (*M_1* = 896.69, *SD* = 69.60; *M_2* = 900.38, *SD* = 43.63). This table also indicates that manual responses were consistently quicker for verification than for falsification for both earlier acquired (*M_1* = 777.82, *SD* = 86.49; *M_2* = 818.20, *SD* = 56.64 vs. *M_1* = 819.10, *SD* = 94.78; *M_2* = 859.89, *SD* = 56.66) and later acquired stimuli (*M_1* = 827.72, *SD* = 105.08; *M_2* = 888.34, *SD* = 60.63 vs. *M_1* = 863.74, *SD* = 103.69; *M_2* = 913.55, *SD* = 58.61). These descriptive statistics suggest that both AoA and the response criterion influenced response times during the picture-name verification task.

Table 5.1 Average response times and error/omission rates for Experiment 3a

Measure	Mean (SD)	Error Rate (SD)
Early acquired average		
By-Item	838.58 (40.17)	3.59 (1.31)
By-Subject	844.58 (64.61)	5.64 (5.74)
Late acquired average		
By-Item	900.38 (43.63)	4.41 (2.00)
By-Subject	896.69 (69.60)	7.36 (3.49)
Early acquired verification		
By-Item	818.20 (56.64)	1.68 (.97)
By-Subject	777.82 (86.49)	2.86 (3.47)
Early acquired falsification		
By-Item	859.89 (56.66)	1.79 (1.25)
By-Subject	819.10 (94.78)	2.64 (2.97)
Late acquired verification		
By-Item	888.34 (60.63)	2.38 (1.18)
By-Subject	827.72 (105.08)	3.91 (2.51)
Late acquired falsification		
By-Item	913.55 (58.61)	2.03 (1.29)
By-Subject	863.74 (103.69)	3.46 (2.02)

Therefore, manual response times were analysed by-item and by-subject using 2 (AoA: early acquired vs. late acquired) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. This revealed that there was a significant main effect of AoA in both the by-subject and by-item analyses accounting for 61% and 59% of the variance respectively, F_1 (1, 21) = 32.381, $p < .001$, partial η^2 = .607; F_2 (1, 33) = 46.905, $p < .001$, partial η^2 = .587. There was also a main effect of the response criteria by-subject and by-item which accounted for 45% and 20% of the variance respectively, F_1 (1, 21) = 32.381, $p < .001$, partial η^2 = .446; F_2 (1, 33) = 8.383, $p < .01$, partial η^2 = .203). However, the interaction between AoA and the response criteria was not significant by-subject or by-item, F (1, 21) = .093, $p > .05$, partial η^2 = .004; F (1, 33) = .980, $p > .05$, partial η^2 = .029). This demonstrates that AoA and the response criteria both exerted significant but independent effects on manual response times during this task. However, later acquired items were no more susceptible to the effects of response criteria than earlier acquired items.

5.4.3 Analysis of Error/Omission Rates

Table 5.1 also demonstrates that error/omission rates were similar across all stimuli types. Indeed, the average number of errors/omissions produced for earlier acquired items (M_1 = 5.64, SD = 5.74; M_2 = 3.59, SD = 1.31) was only slightly lower than the average number of errors/omissions produced for later acquired items (M_1 = 7.36, SD = 3.49; M_2 = 4.41, SD = 2.00). However, Table 5.1 does demonstrate that verification consistently elicited slightly fewer errors than falsification for both earlier acquired (M_1 = 2.86, SD = 3.47; M_2 = 1.68, SD = .97 vs. M_1 = 2.64, SD = 2.97; M_2 = 1.79, SD = 1.25) and later acquired items (M_1 = 3.91, SD = 2.51; M_2 = 2.38, SD = 1.18 vs. M_1 = 3.46, SD = 2.02; M_2 = 2.03, SD = 1.29). These descriptive statistics imply that while AoA did not appear to influence error/omission rates, trials which required falsification were more prone to error/omission than trials which required verification.

Therefore, error/omission rates were also analysed by-item and by-subject using a 2 (AoA: early acquired vs. late acquired) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. This revealed that the main effect of AoA on error/omission rates was not significant by-subject but was significant by-item and accounted for 12% of the variance, F_1 (1, 21) = 2.690, $p > .05$, partial η^2 = .114; F_2 (1, 33) = 4.520, $p < .05$, partial η^2 = .120. The main effect of the response criteria was not significant by-subject or by-item, F_1 (1, 21) = .464, $p > .05$, partial η^2 = .022; F_2 (1, 33) = .310, $p > .05$, partial η^2 = .009. The interaction between AoA and the response criteria was not significant by-subject or by-item, F_1 (1, 21) = .743, $p > .05$, partial η^2 = .005; F_2 (1, 33) = 1.848, $p > .05$, partial η^2 = .053. These findings suggest that neither AoA nor the response criteria have consistent and significant effects on response accuracy.

5.4.4 Analysis of Total Fixation Durations

Table 5.2 presents mean total fixation durations (ms) on earlier and later acquired stimuli during picture-name verification/falsification. This suggests that participants fixated on later acquired items (M_1 = 339.70, *SD* = 73.83; M_2 = 350.54, *SD* = 43.69) for more time than they fixated on earlier acquired items (M_1 = 235.58, *SD* = 33.25; M_2 = 236.36, *SD* = 33.25). There was also a trend for trials which required verification to elicit shorter total fixation durations than trials which required falsification for both earlier acquired items (M_1 = 227.98, *SD* = 45.36; M_2 = 226.57, *SD* = 34.58 vs. M_1 = 245.64, *SD* = 45.63; M_2 = 237.89, *SD* = 37.31) and later acquired items (M_1 = 338.98, *SD* = 78.81; M_2 = 349.95, *SD* = 66.28 vs. M_1 = 339.44, *SD* = 76.61; M_2 =

347.69, *SD* = 64.15). These descriptive statistics suggest that perceptual processing speed was faster for earlier acquired items than later acquired items. It also suggests that verification was a faster cognitive process than falsification.

Table 5.2 Average total fixation durations for Experiment 3a

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Early acquired average	236.56 (33.25)	235.58 (40.94)
Late acquired average	350.54 (43.69)	339.70 (73.83)
Early acquired verification	226.57 (34.58)	227.98 (45.36)
Late acquired verification	349.95 (66.28)	338.90 (78.81)
Early acquired falsification	237.89 (37.31)	245.64 (45.63)
Late acquired falsification	347.69 (64.15)	339.44 (76.61)

Consequently, total fixation durations (ms) were analysed by-item and by-subject using separate 2 (AoA: early acquired vs. late acquired) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. This revealed that there was a significant main effect of AoA on total fixation durations by-subject and by-item accounting for 78% and 84% of the variance respectively, F_1 (1, 21) = 74.817, $p <$ .001, partial η^2 = .781; F_2 (1, 33) = 176.104, $p <$ .001, partial η^2 = .842. However, the main effect of the response criteria on total fixation durations was not significant by-subject or by-item, F_2 (1, 21) = .167, $p >$ .05, partial η^2 = .089; F_2 (1, 33) = .208, $p >$ .05, partial η^2 = .006. The interaction between AoA and the response criteria was not significant by-subject or by-item, F_1 (1, 21) = 1.493, $p >$ .05, partial η^2 = .066; F_2 (1, 33) = .634, $p >$ .05, partial η^2 = .019. Therefore, while participants fixated on later acquired items for significantly more time than they fixated on earlier acquired items, there was no effect of the response criteria on total fixation duration. This supports the findings from Experiment 2a and suggests that AoA exerts a consistent and strong effect on perceptual processing speed as measured by total fixation durations.

5.5 Methodology for Experiment 2b

5.5.1 Design

Experiment 3b utilised a 2 (frequency: low frequency vs. high frequency) x 2 (response criteria: verification vs. falsification) repeated measures design. Therefore, the independent variables were word frequency and the response criterion. The dependent variables were identical to those of Experiment 3a.

5.5.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 3b, participants consisted of 22 (3 males and 19 females) students and staff from the University of Worcester. Participants ranged from 18 to 45 years of age with a mean age of 24.86 (6.59).

5.5.3 Materials

The materials and word frequency stimuli sets for Experiment 3b were identical to those discussed in Chapter 2, Section 2.4.3.2. However, when an item was paired with an incompatible name, this name was drawn from the same stimuli set. This meant that incompatible items were always paired with a word with similar properties to the correct word.

5.5.4 Procedure

The procedure was identical to that used in Experiment 3a.

5.6 Results for Experiment 3b

5.6.1 Data Preparation

Data preparation processes were discussed in Chapter 2, Section 2.5.

5.6.2 Analysis of Response Times

Table 5.3 presents the descriptive statistics for average manual response times by-item and by-subject for low frequency and high frequency items. This suggests that average response times were similar for low frequency items (M_1 = 823.61, *SD* = 67.23; M_2 = 819.36, *SD* = 32.59) and high frequency items (M_1 = 824.87, *SD* = 60.47; M_2 = 812.23, *SD* = 30.79). However, it also suggests that trials which required verification elicited faster manual response times than the trials which required falsification for both low frequency items (M_1 = 800.90, *SD* = 72.76; M_2 = 812.42, *SD* = 55.14 vs. M_1 = 847.37, *SD* = 71.74; M_2 = 839.44, *SD* = 32.68) and high frequency items (M_1 = 806.25, *SD* = 66.15; M_2 = 802.90, *SD* = 42.00 vs. M_1 = 844.68, *SD* = 66.87; M_2 = 839.93, *SD* = 37.95). These descriptive statistics suggest that while word frequency did not appear to influence manual response times during picture-name verification/falsification, verification was characterised by faster perceptual process than falsification.

Table 5.3 Response times and error/omission rates for Experiment 3b

Measure	Mean (SD)	Error Rate (SD)
Low frequency average		
By-Item	819.36 (32.59)	2.71 (1.92)
By-Subject	823.61 (67.23)	4.23 (3.15)
High frequency average		
By-Item	812.23 (30.79)	2.62 (1.83)
By-Subject	824.87 (60.47)	2.09 (1.66)
Low frequency verification		
By-Item	812.42 (55.14)	1.29 (1.43)
By-Subject	800.90 (72.76)	2.14 (2.19)
Low frequency falsification		
By-Item	839.44 (32.68)	1.41 (1.18)
By-Subject	847.37 (71.74)	4.05 (3.48)
High frequency verification		
By-Item	802.90 (42.00)	1.27 (1.05)
By-Subject	806.25 (66.15)	1.94 (2.01)
High frequency falsification		
By-Item	839.93 (37.95)	1.35 (1.20)
By-Subject	844.68 (66.87)	2.00 (2.07)

Consequently, manual response times were analysed by-item and by-subject using separate 2 (frequency: low vs. high) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. The main effect of word frequency on manual response times was not significant by-subject or by-item, F_1 (1, 21) = .051, $p > .05$, partial $\eta^2 = .002$; F_2 (1, 33) = .266, $p > .05$, partial $\eta^2 = .008$. However, the main effect of the response criteria was significant by-subject and by-item accounting for 57% and 33% of the variance respectively, F_1 (1, 21) = 27.537, $p < .001$, partial $\eta^2 = .567$; F_2 (1, 33) = 16.504, $p < .001$, partial $\eta^2 = .333$. The interaction between word frequency and the response criteria was not significance by-subject or by-item, F_1 (1, 21) = .393, $p > .05$, partial $\eta^2 = .018$; F_2 (1, 33) = .651, $p > .05$, partial $\eta^2 =$

.019. This suggests that the response criteria exerted a more robust influence on manual response times than word frequency. Furthermore, verification was a significantly faster cognitive process than falsification.

5.6.3 Analysis of Error/Omission Rates

Table 5.3 also demonstrates that participants produced higher error/omission rates for low frequency items (M_1 = 4.23, *SD* = 3.15; M_2 = 2.71, *SD* = 1.92) than those produced for high frequency items (M_1 = 2.09, *SD* = 1.66; M_2 = 2.62, *SD* = 1.83). Furthermore, it also suggests that trials which required verification elicited slightly fewer errors than trials which required falsification for both low frequency items (M_1 = 2.14, *SD* = 2.19; M_2 = 1.29, *SD* = 1.43 vs. M_1 = 4.05, *SD* = 3.48; M_2 = 1.41, *SD* = 1.18) and high frequency items (M_1 = 1.94, *SD* = 2.01; M_2 = 1.27, *SD* = 1.05 vs. M_1 = 2.00, *SD* = 2.07; M_2 = 1.35, *SD* = 1.20). These descriptive statistics suggest that word frequency and the response criterion may have exerted effects on error/omission rates during picture-name verification/falsification.

Error/omission rates were analysed by-item and by-subject using separate 2 (frequency: low vs. high) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. This revealed that the main effect of word frequency on error/omission rates was significant by-subject and accounted for 49% of the variance, but was not significant by-item, F_1 (1, 21) = 19.781, $p < .001$, partial η^2 = .485; F_2 (1, 33) = .040, $p > .05$, partial η^2 = .001. The main effect of the response criteria on error/omission rates was significant by-subject and accounted for 30% of the variance but was not significant by-item, F_1 (1, 21) = 9.147, p = .006, partial η^2 = .303; F_2 (1, 33)

= .302, $p > .05$, partial $\eta^2 = .009$. The interaction between frequency and the response criteria was significant in the by-subject analysis and accounted for 18% of the variance but was not significant by-item, F_1 (1, 21) = 4.450, $p < .05$, partial $\eta^2 = .175$; F_2 (1, 33) = .006, $p > .05$, partial $\eta^2 = .001$. Post-hoc tests with an adjusted alpha value of 0.01 revealed that low frequency verification produced significantly more errors/omissions than high frequency falsification by-subject but not by item, t_1 (21) = 2.978, $p < .01$; t_2 (33) = .284, $p > .05$. Furthermore, low frequency falsification produced significantly more errors than low frequency falsification produced significantly more errors than high frequency verification by-subject but not by-item, t_1 (21) = 4.742, $p < .001$; t_2 (33) = .596, $p > .05$. No other significant differences were observed (all p > 0.05). Therefore, the significant differences were restricted to the by-subject analysis. This suggests that participants found it more difficult to process low frequency items if a trial required falsification than when a trial required verification. However, this result should be interpreted with caution due to the lack of similar results in the by-item analysis. Therefore, despite word frequency not exerting an effect on response latencies, it did influence response accuracy.

5.6.4 Analysis of Total Fixation Durations

Table 5.4 presents descriptive statistics for mean total fixation durations (ms) on low and high frequency stimuli during the picture-name verification/falsification task. This revealed that average total fixation durations on low frequency items (M_1 = 280.15, *SD* = 88.19; M_2 = 277.45, *SD* = 33.05) was similar to those on high frequency items (M_1 = 274.28, *SD* = 72.70; M_2 = 273.13, *SD* = 30.93). It also suggested that total fixation durations on trials requiring verification were similar to those on trials requiring falsification for both low frequency items (M_1 = 271.60, *SD* = 89.98; M_2 = 277.44, *SD* = 44.08 vs. M_1 = 289.20, *SD* = 87.70; M_2 = 286.57, *SD* = 41.71) and high frequency items (M_1 = 274.72, *SD* = 74.32; M_2 = 273.53, *SD* = 34.00 vs. M_1 = 273.07, *SD* = 76.76; M_2 = 271.52, *SD* = 42.29). These descriptive statistics suggest that neither word frequency nor the response criterion influenced total fixation durations during the picture-name verification/falsification task.

Table 5.4 Average total fixation durations for Experiment 3b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency average	277.45 (33.05)	280.15 (88.19)
High frequency average	273.13 (30.93)	274.28 (72.70)
Low frequency verification	277.44 (44.08)	271.60 (89.98)
High frequency verification	273.53 (34.00)	274.72 (74.32)
Low frequency falsification	286.57 (41.71)	289.20 (87.70)
High frequency falsification	271.52 (42.29)	273.07 (76.76)

However, to identify any significant effects of word frequency and the response criterion, total fixation durations were analysed by-subject and by-item using a 2 (word frequency: high frequency vs. low frequency) x 2 (response criteria: verification vs. falsification) repeated measures analyses of variance. The main effect of word frequency on total fixation duration was not significant by-subject or by-item, F_1 (1, 21) = 1.104, $p > .05$, partial $\eta^2 = .050$; F_2 (1, 33) = 1.398, $p > .05$, partial $\eta^2 = .041$. The main effect of the response criteria on total fixation durations was not significant by-subject or by-item, F_1 (1, 21) = 2.534, $p > .05$, partial $\eta^2 = .108$; F_2 (1, 33) = .254, $p > .05$, partial $\eta^2 = .008$. There was no significant interaction between word frequency and the response criteria by-subject or by-item, F_1 (1, 21) = 3.563, $p > .05$, partial $\eta^2 = .145$; F_2 (1, 33) = 1.055, $p > .05$, partial $\eta^2 = .031$. Therefore, neither word frequency nor the response criteria exerted a significant effect on total fixation duration during picture-name verification/falsification.

5.7 Discussion of Results for Experiments 3a and 3b

The experiments reported in this chapter investigated the effects of AoA, word frequency and the response criteria on manual response times, total fixation durations and error/omission rates during an adaptation of the picture-name verification/falsification task. The experiments were the first to investigate these effects using picture-name verification/falsification in conjunction with eye-tracking. This enabled the researcher to expand on the findings reported in Chapters 3 and 4 and work further towards meeting the aims and objectives of this thesis. Consequently, this chapter has facilitated the identification of potential loci of AoA during perceptual processing, semantic processing and indirect lexical access (Catling & Johnston, 2009; Holmes & Ellis, 2006). Furthermore, interpreted in context of Experiment 1a and Experiment 2a, Experiment 3a enabled the researcher to differentiate and explore the potential loci of AoA effects routed at the perceptual level of processing (Chapter 3), between perceptual and semantic processing (Chapter 4) and between semantic and lexical processing. This distinction is explored fully in Chapter 9 following a comparison of effect sizes across all of the experimental paradigms reported in this thesis. The implications of the results from Experiment 3a for the hypotheses are summarised in Table 5.5.

Table 5.5 Implications for the hypotheses of Experiment 3a

Hypothesis	Evidence
Earlier acquired items will elicit significantly faster manual response times and shorter total fixation durations than later acquired items.	Supported
Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items.	Partially supported
Trials requiring verification will elicit significantly faster manual response times and shorter total fixation durations than trials requiring falsification	Partially supported
Trials requiring verification will elicit significantly fewer errors/omissions than trials requiring falsification.	Not supported
Trials requiring falsification will be significantly more susceptible to the effects of AoA than trials requiring verification	Not supported

Consistent with the hypotheses, Experiment 3a demonstrated that AoA exerted significant but independent effects on manual response times and total fixation durations during an adaptation of the picture-name verification/falsification task. Therefore, participants processed earlier acquired items faster than they processed later acquired items. There was also a significant effect of AoA on error/omission rates in the by-item analysis suggesting that AoA effects may also exert some influence on response accuracy. However, this finding should be interpreted with caution due the absence of a significant effect of AoA on errors/omissions in the by-subject analysis.

While the significant effect of AoA on response times provides support for the study conducted by Catling and Johnston (2006a), this research has also substantially expanded these findings. Indeed, the effects of AoA on both manual and automatic responses supports the theory that there may be at least two loci of AoA with the first being during perceptual processing and the second occurring prior to articulation (Holmes & Ellis, 2006; Johnston & Barry, 2006; Moore, Smith-Spark & Valentine; 2004). Furthermore, interpreted in context with the findings from Experiment 1a and existing literature, there appear to be loci of AoA effects in perceptual, semantic and early semantic-lexical processing (Ellis, 2012; Johnston & Barry, 2006; Juhasz, 2005). Indeed, it is notable that when consulting the partial eta squared values reported in these chapters, AoA effects observed in picture-name verification/falsification (Experiment 2a) were larger than those observed in picture-category verification/falsification (Experiment 1a). This not only provides support for the multi-loci perspective but also supports the proposition that AoA effects may accumulate as each additional level of processing is completed (Catling & Johnston, 2009; Ellis & Lambon Ralph, 2000). Indeed, Catling and Johnston (2006a) also observed that the AoA effects observed during picture-name verification were smaller than those observed during picture-naming. This suggests that there may also be stronger loci of these effects in the last stages of processing and further research is required to explore these differential effect sizes. However, effect sizes are fully compared and contrasted in Chapter 9, using the complete response time and total fixation duration data collected across all of the experimental paradigms employed during this programme of research.

The effects of AoA were also independent of the significant main effects of the response criteria. This is inconsistent with the perspective that verification and falsification can be differentially affected by AoA but supports the findings from Experiment 2a (picture-category verification/falsification). Indeed, AoA and the response criteria exerted significant but independent effects on manual response times in both picture-category verification/falsification and picture-name verification/falsification. However, contrary to the hypotheses there was no effect of the response criteria on total fixation durations during picture-name verification/falsification. This is inconsistent with the results from Experiment 2a.

Indeed, interpreted in the context of Experiment 2a, this suggests that the response criteria may only influence perceptual processing speed during tasks which require more extensive semantic processing than picture-name verification/falsification (Yee & Sedivy, 2006).

The implications for the hypotheses which were proposed for Experiment 3b are identified in Table 5.6. It is also notable that there were no significant effects of word frequency on manual response times or fixation durations and there was only limited evidence for an effect of word frequency on response accuracy. Similar to the findings for Experiment 2b reported in Chapter 4, Experiment 3b also revealed that the response criteria exerted a significant effect on manual response times but not total fixation durations during picture-name verification/falsification. This again suggests that response criteria exert a stronger influence during tasks which require more extensive semantic processing, such as during picture-category verification/falsification (Meyer, Roelofs & Levelt, 2003; Meyer, Sleiderink & Levelt, 1998; Shillcock, 2007; Underwood, Jebbett & Roberts, 2004). Furthermore, when considered in context of the findings from Experiments 2a and 2b (Chapter 4), the findings from Experiments 3a and 3b offer further support for the argument that AoA effects are not reducible to the effects of word frequency or the response criteria used during verification/falsification tasks.

The findings reported in this chapter also support previous studies which have observed significant AoA effects during tasks which require perceptual-semantic processing and semantic-lexical processing (Johnston & Barry, 2006; Juhasz, 2005; Juhasz & Rayner, 2003, 2004, 2006). The pattern of results observed across Experiments 1a and 2a are most consistent with the multi-loci perspective of AoA

(Ellis, 2012; Ellis & Lambon Ralph, 2000). Indeed, proponents of the PCH and the SH would both predict AoA effects at a specific level of processing, while the multi-loci perspective can explain effects across the cognitive system. However, further research is required to identify whether AoA effects are also evident and potentially larger in magnitude in tasks which require access to the later stages of lexical retrieval and articulation. Indeed, AoA and word frequency effects are often most evident and consistent during tasks which require phonological retrieval and articulation, such as in the case of picture naming and word reading (Ellis, 2012; Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Juhasz, 2005; Zevin & Seidenberg, 2000, 2004).

Table 5.6 Implications for the hypotheses of Experiment 3b

Hypothesis	Evidence
High frequency items will elicit significantly faster manual response times and shorter total fixation durations than low frequency items.	Not supported
High frequency items will elicit significantly fewer errors/omissions than low frequency items.	Not supported
Trials requiring verification will produce significantly faster manual response times and shorter total fixation durations than trials requiring falsification.	Partially supported
Trials requiring verification will elicit significantly fewer errors/omissions than trials requiring falsification.	Partially supported
Trials that require falsification will be significantly more susceptible to the influence of word frequency than trials requiring verification.	Partially supported

For example, Catling and Johnston (2006a) observed that AoA effects were significantly larger during picture naming than during picture-name verification. However, there were a number of limitations with these experiments, including that only the data for verification was analysed and the effects of word frequency were controlled rather than investigated. As discussed in previously sections, proponents of the multi-loci perspective argue that AoA effects are most pronounced when word frequency does not exert a significant effect (Ellis & Lambon Ralph, 2000). Indeed, Bonin, Chalard, Méot, and Fayol (2002) and Bonin, Peereman, and Fayol (2001) both identified that AoA was a significant predictor of both written and spoken picture naming while word frequency was not. However, it must be noted that the majority of studies which have investigated the effects of word frequency on picture naming have identified significant effects of word frequency on processing speed and accuracy (Barry et al., 1997; Ellis & Morrison, 1998; Johnston & Barry, 2006; Juhasz, 2005). Interestingly, Bonin, Peereman and Fayol (2001) argue that their measure of word frequency might not accurately reflect the frequency of the items in French. It is also notable that the use of multiple regression in AoA research has been highly criticised due to poor adherence to the paramedic assumption of this test, the increased risk Type I and Type II error (Lewis, 2006; Zevin & Seidenberg, 2002, 2004).

Therefore, the experiments reported in Chapter 6 expand on the findings reported in Chapters 3-5 by assessing the effects of AoA and word frequency during picture naming. This experimental paradigm was adopted because it is a useful technique for assessing AoA effects at perceptual, semantic, indirect semantic-lexical, lexical retrieval and articulation levels of processing (Barry et al., 1997; Ellis & Morrison, 1998; Johnston & Barry, 2006; Juhasz, 2005). To address the limitations of previous research, the stimuli sets were identical to those used in Experiments 1a – 3b. Furthermore, total fixation durations were also recorded to enable the researcher to identify any perceptual effects of AoA and word frequency during this task.

5. 8 Chapter Conclusion

Chapter 5 has reported two semi-factorial experiments which investigated the effects of AoA, word frequency and the response criteria on manual response times, total fixation durations and error/omission rates during an adapted picture-name verification/falsification task. These experiments revealed that AoA and the response criteria exerted significant but independent effects on manual response times. In contrast, only AoA influenced total fixation duration. Furthermore, there were no consistent effects of AoA, word frequency and the response criteria on error/omission rates. The significant and independent effects of AoA on response times and total fixation durations during both picture-category verification/falsification (Chapter 4) and picture-name verification/falsification (Chapter 5) subsequently suggest that there are potential loci of AoA effects between perceptual-semantic and semantic-lexical levels of processing. However, picture-name verification/falsification tasks do not require articulation, which previous studies have frequently linked to stronger AoA effects than those observed during tasks which require semantic processing and the indirect route to lexical access (Johnston & Barry, 2006; Juhasz, 2006). Furthermore, frequency-related AoA effects are also observed more frequently during tasks which require articulation than during tasks which do not require this level of processing (Brysbaert & Ghyselinck, 2006). This suggests that further research is required to investigate the effects of AoA and word frequency during tasks which require lexical retrieval and articulation.

Consequently, Chapter 6 reports two semi-factorial experiments which investigated the effects of AoA and word frequency on verbal response times, total fixation durations and error/omission rates during immediate picture naming. This experimental paradigm was chosen because it enabled the researcher to investigate the potential loci of AoA and word frequency effects during perceptual processing, semantic processing, indirect lexical access, lexical retrieval and articulation. Therefore, Chapter 6 expands on the principles and findings reported in Chapters 3 -5 to investigate whether AoA and word frequency influenced the later stages of lexical processing. However, methodological elements such as the stimuli sets, display times and the population from which the sample were obtained were identical to the previous experiments. This facilitated the comparison of AoA and word frequency effects across the different experimental paradigms.

Chapter 6: Immediate Picture Naming

6.1 Chapter Overview

Chapter 3 reported experiments which investigated AoA and word frequency on visual duration thresholds and error/omission rates during an object recognition task while Chapter 4 and Chapter 5 reported experiments which investigated the effects of AoA and word frequency on manual response times, total fixation durations and error/omission rates during picture-category verification/falsification and picture-name verification/falsification. These experiments provided support to the proposition that there are loci of AoA effects prior to lexical retrieval and articulation. Indeed, the findings suggested that AoA exerts a significant effect during perceptual-semantic and semantic-lexical processing (Catling & Johnston, 2009; Ellis & Lambon Ralph, 2000). This is inconsistent with both the PCH and the SH which can only explain effects during one localised component of processing, but it is consistent with the multi-loci perspective in which AoA effects are routed in the connections between levels of processing system rather at a specific stage (Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008). Furthermore, the effects of AoA which were observed during picture-name verification/falsification were stronger than those observed during picture-category verification/falsification. This lends support to the multi-loci principle that AoA effects will be stronger in tasks which require arbitrary mapping between levels of processing (Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006).

However, it is notable that word frequency did not exert a significant, consistent effect during picture-category verification/falsification or picture-name verification/falsification. This may be due to these experimental paradigms not requiring processing beyond semantic properties and early lexical access (Brysbaert & Ghyselinck, 2006; Zevin & Seidenberg, 2002, 2004). Indeed, frequency-independent AoA effects are typically reported during tasks which have a prominent semantic focus, while frequency-related AoA effects are more prevalent in tasks which have a lexical focus (Brysbaert & Ghyselinck, 2006; Ellis, 2012; Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Juhasz, 2005; Zevin & Seidenberg, 2000, 2004). Therefore, further research is required to investigate whether AoA and word frequency influence performance during tasks which require the later stages of lexicalisation (e.g. lexical retrieval and articulation).

However, it is also possible to draw distinctions between tasks which require indirect lexical access, lexical retrieval and articulation (e.g. picture naming) and tasks which require direct lexical access, lexical retrieval and articulation (e.g. word reading). These tasks follow different routes to the mental lexicon and as such they may be differentially affected by AoA and word frequency (Barry et al., 1997; Catling & Johnston, 2009; Ellis & Morrison, 1998; Johnston & Barry, 2006; Juhasz, 2005). For example, as outlined in Chapter 1 and Chapter 2, the PCH would predict that word reading would elicit significantly stronger frequency-related AoA effects than picture naming. Word reading in English relies on spelling-to-sound consistency to enable participants the reintegrate the components of the word form stored in the mental lexicon prior to retrieval and articulation (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Garlock, Walley, & Metsala, 2001; Moore, Smith-Spark, &

Valentine, 2004). According to the PCH, earlier acquired items gain a processing advantage during this stage because later acquired items require more effortful integration of more widely distributed lexical components than earlier acquired items (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Garlock, Walley, & Metsala, 2001; Moore, Smith-Spark, & Valentine, 2004). In contrast, there is no direct correspondence between a pictorial stimulus and the corresponding label stored in the mental lexicon (Bakhtiar & Weekes, 2014; Lambon Ralph & Ehsan, 2006). According to the principles of the multi-loci perspective, this arbitrary mapping should result in stronger AoA effects during picture naming than during word reading (Catling & Johnston, 2009; Ellis & Lambon Ralph, 2000). However, if word frequency exerts a significant effect during picture naming and word reading, the principles of the multi-loci perspective would suggest that these effects would be smaller in magnitude than the frequency-independent effects which were observed during picture-category verification/falsification and picture-name verification/falsification (Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2009; Ellis, 2012; Ellis & Lambon Ralph, 2000). Therefore, Chapter 5 examined the effects of AoA and word frequency during picture naming while Chapter 6 investigates the effects of AoA and word frequency during word reading. This demonstrates how the programme of research presented in this thesis was designed to systematically differentiate between AoA and word frequency effects across a variety of processing stages to identify which theoretical perspective is most parsimonious.

Consequently, Chapter 6 extends on the principles and findings of Chapter 3, Chapter 4 and Chapter 5 by reporting two semi-factorial experiments which investigated the effects of AoA and word frequency on verbal response times, total fixation durations and error/omission rates during immediate picture naming. This research paradigm was chosen due to it enabling the researcher to investigate the potential loci of AoA and word frequency during a task which required perceptual processing, semantic processing, indirect lexical access, lexical retrieval and articulation (Barry, Morrison & Ellis, 1997; Belke, Brysbaert, Meyer & Ghyselinck, 2005; Bodka et al., 2003; Ellis, Burani, Izura, Bromiley & Venneri, 2006; Lambon Ralph & Ehsan, 2006; Roelofs, 2007; Yee & Sedivy, 2006). Subsequently, this chapter reports frequency-independent AoA effects during picture naming. Furthermore, the effects of AoA on response times during immediate picture naming were stronger than those observed during picture-category verification/falsification and picture-name verification/falsification. These findings are interpreted in the chapter discussion with reference to how these findings support the multi-loci perspective of AoA effects.

6.2 Introduction to Experiments 4a and 4b

The picture naming paradigm was chosen due to it enabling the researcher to assess potential loci of AoA and word frequency effects during indirect lexical access and articulation, in addition to further assessing potential loci at the perceptual and semantic levels of processing (Belke, Brysbaert, Meyer & Ghyselinck, 2005; Catling & Johnston, 2009; Lambon Ralph & Ehsan, 2006). Furthermore, as outlined in Chapter 1, Section 1.2.3, picture naming is compatible with the multi-loci principles of arbitrary mapping between levels of processing and the use of multiple systems which have been acquired through gradual, interleaved learning (Ellis, Burani, Izura, Bromiley & Venneri, 2006; Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006). Consequently, if the multi-loci perspective and experimental design are valid and reliable, the picture naming experimental paradigm should enable the researcher to identify any significant AoA and word frequency effects which emerge during these cognitive processes.

Similar to the picture-category verification/falsification (Chapter 4) and picture-name verification/falsification (Chapter 5) paradigms, picture naming requires successful perceptual processing of visually presented stimuli, object recognition processes and semantic processing. Furthermore, similar to the picture-category verification/falsification and picture-name verification/falsification paradigms, picture naming also requires indirect lexical access (Barry, Morrison & Ellis, 1997; Belke, Brysbaert, Meyer & Ghyselinck, 2005; Catling & Johnston, 2009). For example, in picture naming, the mapping between the visually presented image and the corresponding label stored in the mental lexicon is arbitrary and determined by the semantic properties of the stimuli rather than orthographic properties as in the case of printed words. Therefore, picture naming is a particularly useful experimental paradigm for assessing psycholinguistic effects during semantic-lexical encoding (Bonin, Fayol & Chalard, 2001; Ellis, Izura, Bromiley & Venneri, 2006; Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006). However, unlike the tasks reported in the previous experimental chapters, picture naming also requires articulation. This suggests that picture naming is an ideal experimental paradigm to enable researchers to examine the effects of AoA and word frequency during perceptual processing, semantic processing, indirect lexical access, lexical retrieval and articulation.

However, picture naming is a complex cognitive task which requires participants to engage in several processes. Participants must perceive the object in the visual field and actively attend this stimulus by directing their attention towards the item (Roelofs, 2007; Yee & Sedivy, 2006). For successful object recognition, participants must then recognise the stimulus as an object and understand what it represents at a conceptual level (Barry, Morrison & Ellis, 1997). For example, should a picture of a particular breed of dog be presented, participants must identify that this image represents the archetypal concept of ‘dog’ in addition to the sub-category of the particular breed. The next stage of successful picture-naming requires that participants select the correct lemma from a collection of conceptually similar items, the correct lexemes from similar morphological units and the corresponding phonemes from those stored in the mental lexicon (Jescheniak & Levelt, 1994; Kempen & Huijbers, 1983; Levelt, 1989). Participants must then synthesis these components, retrieve this information and articulate it by coordinating their vocal apparatus[35]. This demonstrates that picture naming is a complex experimental paradigm which bridges the gap between tasks which do not require lexicalisation, tasks which rely upon the semantic route to lexicalisation and tasks which require the direct route to lexicalisation (Bakhtiar & Weekes, 2014; Lambon Ralph & Ehsan, 2006).

[35] Vocal apparatus refers to all structures which are involved in the production of speech sounds including the lips, teeth, tongue and larynx.

Indeed, picture naming is a commonly used experimental technique in the AoA and word frequency research (Bonin, Méot, Mermillod, Ferrand, & Barry, 2009; Brysbaert & Ghyselinck, 2006; Catling, Dent, Preece, & Johnston, 2013; Johnston & Barry, 2006; Kittredge et al., 2008; Raman, 2011). However, there are a number of limitations evident in previous studies which the researcher resolved in Experiments 3a and 3b. For example, a number of studies have investigated the effects of AoA and word frequency using non-factorial designs in which variables are controlled post hoc during the analyses rather than during research design (Barry, Morrison & Ellis, 1997; Belke, Brysbaert, Meyer & Ghyselinck, 2005; Bodka et al., 2003; Bonin, Chalard, Méot & Fayol, 2002). This lack of control during research design can make picture naming susceptible to the confounding influence of other psycholinguistic properties (Lewis, 2006; Zevin & Seidenberg, 2002). For example, using stepwise regression, Belke, Brysbaert, Meyer and Ghyselinck (2005) investigated the effects of AoA during picture naming and word reading. They identified significant effects of AoA on response times during both picture naming and word reading; although the effect of AoA was stronger in picture naming than in word reading. Furthermore, they also identified that late acquired items were more susceptible to interference than earlier acquired items. These results are compatible with the multi-loci perspective due to picture naming relying on arbitrary mapping and word reading relying on transparent mapping (Ellis, Burani, Izura, Bromiley & Venneri, 2006; Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006). However, although this study provided valuable insights into AoA effects, Belke, Brysbaert, Meyer and Ghyselinck (2005) admitted that frequency was not adequately controlled and subsequently accounted for some of the variance previously explained by AoA. As discussed in the previous chapters, tasks which require lexicalisation usually frequency-related AoA effects which are usually smaller in magnitude than frequency-independent AoA effects (Brysbaert & Ghyselinck, 2006; Ellis, 2012; Ellis & Lambon Ralph, 2000). This may explain the weaker AoA effect during word reading if these findings were confounded by word frequency. Furthermore, despite the researchers reanalysing their results by varying the order in which variables were entered into their analyses, a large proportion of the variance remained unexplained throughout the analyses. This implies that results may have been confounded by other psycholinguistic properties which were not examined or controlled.

Indeed, in another non-factorial study which investigated the effects of AoA and word frequency during picture naming, Barry, Morrison and Ellis (1997) identified that the majority of the variance in response times was explained by word frequency, the interaction between AoA and word frequency and picture-name agreement. However, AoA did exert a significant effect on response times in one-tailed tests. This finding may also be due to the confounding effects of word frequency (Ellis & Lambon Ralph, 2000). Indeed, Bodka et al (2003) identified AoA and word frequency effects for picture naming in English and Greek when using a stimuli set consisting of 100 items in both the analysis of variance and multiple regression. However, while the effects of AoA were relatively consistent the effects of word frequency varied according to which measure was used in the regression analysis. This implies that the effect of word frequency was not reliable. Therefore, further research is required to investigate the effects of AoA and word frequency during picture naming when more control is exerted over the stimuli set characteristics during research design.

It is notable that several studies employing factorial and semi-factorial designs in picture naming experiments have detected significant AoA effects which are substantially stronger than those detected for word frequency (Brysbaert & Ghyselinck, 2006; Cuetos, Alverez, Gonzalez-Nosti, Méot & Bonin, 2006). For example, Bonin, Fayol and Chalard (2001) identified significant effects of AoA during picture naming while word frequency did not exert a significant independent effect. Furthermore, Cuetos et al. (2006) observed significant effects of AoA across five picture-naming experiments in which four were factorial and one non-factorial. In contrast, the effects of word frequency were primarily restricted to the by-subject analyses implying that participant variables may explain these frequency effects. These findings imply that AoA, rather than word frequency, influences performance during picture-naming tasks when stimuli sets are rigorously controlled.

Therefore, Chapter 6 reports two semi-factorial experiments which investigated the effects of AoA and word frequency during an immediate picture naming task. This experimental paradigm enabled the researcher to orthogonally manipulate AoA and word frequency while controlling the effects of word length, imageability, familiarity, concreteness and picture-name agreement thereby improving experimental control. Furthermore, methodological elements such as the stimuli sets, display times and the population from which the sample were identical to that of Experiments 1a - 3b. This enabled the researcher to compare findings across all of the experimental paradigms reported in this thesis. Furthermore, drawing a distinction between AoA and word frequency effects during picture naming and word reading may also present significant theoretical implications concerning the loci of these effects. Indeed, dissociation between the effects observed during direct lexical access and those observed during indirect lexical access would suggest the loci of AoA are routed in the connections between levels of processing rather than at a specific stage. Therefore, the experimental design used during Experiments 3a and 3b also enabled the researcher to compare and contrast the effects of AoA and word frequency during picture naming and word reading (Chapter 7).

6.2.1 Hypotheses for Experiment 4a

Three hypotheses were formulated for Experiment 4a based on the insights provided by the literature reported in Chapter 1 and the multi-loci perspective:

- Earlier acquired items will elicit significantly faster verbal responses than later acquired items.
- Earlier acquired items will elicit significantly shorter total fixation durations than later acquired items.
- Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items.

6.2.2 Hypotheses for Experiment 4b

Three hypotheses were also formulated for Experiment 4b based on the literature reported in Chapter 1 and the multi-loci perspective:

- High frequency items will elicit significantly faster verbal responses than low frequency items.
- High frequency items will elicit significantly shorter total fixation durations than low frequency items.
- High frequency items will elicit significantly fewer errors/omissions than low frequency items.

6.3 Methodology for Experiment 4a

5.3.1 Design

Experiment 4a utilised a repeated measures design. Therefore, the independent variable was AoA (early vs. late acquired). The first dependent variable was verbal response times (ms). This was operationalised as the difference between the time at which the critical item was presented on the screen and the onset of a verbal response as recorded by a microphone. The second dependent variable was error/omission rate as operationalised as the total number of times the participants provided an incorrect answer, failed to produce a response while the critical item remained on the screen or produced a response which was beyond two standard deviations from the mean. The final dependent variable was the total fixation duration (ms). This was operationalised as the total amount of time participants spent looking directly at the critical item while it remained on the screen regardless of the number of times participants shifted their gaze during the trial.

6.3.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 4a, participants consisted of 22 (4 males and 18 females) students and staff from the University of Worcester. Participants ranged from 18 to 48 years of age with a mean age of 22.86 (7.21) years. However, total fixation duration data was only available for 20 of the participants due to movement during the experimental task.

6.3.3 Materials

The materials and AoA stimuli sets for Experiment 4a were identical to those discussed in Chapter 2, Section 2.4.3.1.

6.3.4 Procedure

The calibration of the eye-tracking equipment was described in Chapter 2, Section 2.4.5. After the calibration was complete, participants were instructed to limit their bodily movement throughout the experiment before pressing the spacebar to proceed to the standardised written instructions. When participants understood these instructions they were instructed to press the space bar to complete 6 practice trials. The 68 critical trials followed automatically. For each trial participants viewed a fixation cross in the centre of the screen for 2000ms. The target item was then presented in the centre of the screen for 1500ms and participants were required to say the objects name while it remained on the screen by speaking clearly into the microphone. The experimenter recorded errors or omissions manually. No immediate feedback was provided after the trials although there was an inter-trial interval of 2000ms which began at the detection of a verbal response. The order of critical trials was randomised to reduce order, practice or boredom effects. After completing the experiments participants were provided with a verbal and standardised written debriefing. Figure 6.1 presents screenshots of the calibration grid, critical trial structure and debriefing for the picture naming experiment. A trial consisted of the third, fourth and fifth screenshot.

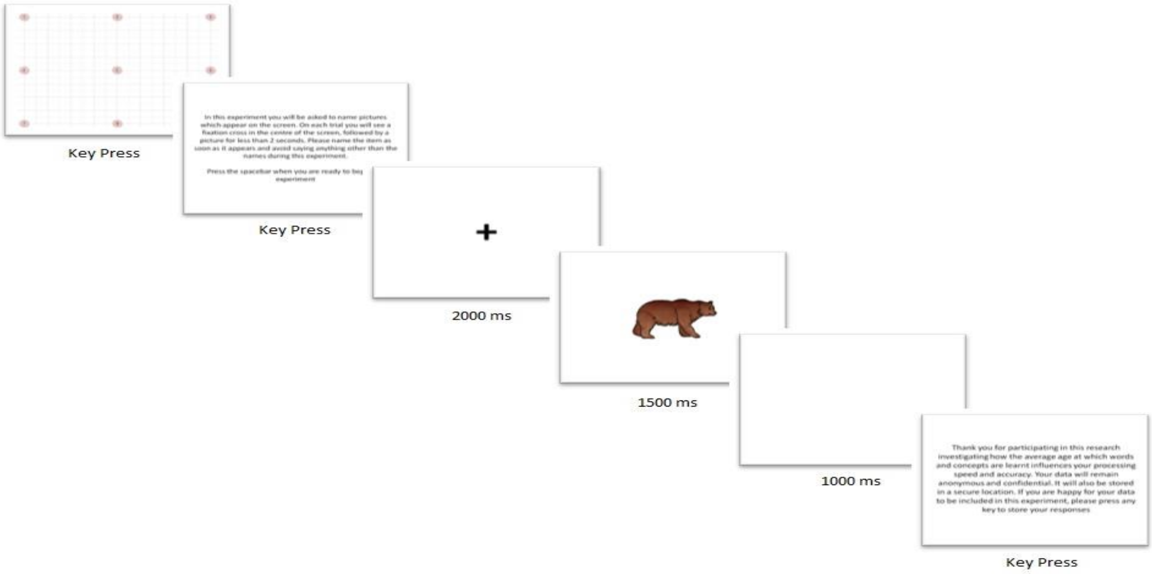

Figure 6.1 The procedure for picture naming tasks

6.4 Results for Experiment 4a

6.4.1 Data Preparation

Data preparation procedures were discussed in Chapter 2, Section 2.5.

6.4.2 Analysis of Response Times

Table 6.1 presents the descriptive statistics for average verbal response times (ms) produced for earlier and later acquired items during picture naming. This demonstrates that on average participants named earlier acquired items (M_1 = 631.93, SD = 48.47; M_2 = 630.31, SD = 35.09) faster than they named later acquired items (M_1

= 776.03, *SD* = 67.35; M_2 = 772.49, *SD* = 46.86). This suggests that AoA exerted an influence on verbal response times during the picture-naming task.

Consequently, to maintain consistency with the analyses performed in the previous chapters, verbal response times for earlier and later acquired items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed significant main effects of AoA on verbal response times by-subject and by-item, which accounted for 88% and 84% of the variance respectively; F_1 (1, 21) = 156.338, $p < .001$, partial $\eta^2 = .882$; F_2 (1, 33) = 171.181, $p < .001$, partial $\eta^2 =$ .838. Therefore, verbal responses were significantly faster for earlier acquired items than they were for later acquired items, demonstrating a strong AoA effect during picture naming. This suggests that AoA exerted a significant effect during indirect lexical access and subsequent articulation.

Table 6.1 Average response times and error/omission rates for Experiment 4a

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Early acquired response time	630.31 (35.09)	631.93 (48.47)
Late acquired response time	772.49 (46.86)	776.03 (67.35)
Early acquired error/omission rates	4.18 (1.80)	6.55 (5.43)
Late acquired error/omission rates	5.24 (1.91)	8.00 (4.61)

6.4.3 Analysis of Error/Omission Rates

Table 6.1 also presents the descriptive statistics for average error/omission rates produced for earlier and later acquired items during picture naming. This demonstrates that participants made fewer errors while processing earlier acquired items (M_1 = 6.55, *SD* = 5.43; M_2 = 4.18, *SD* = 1.80) compared to when they processed later acquired items

(M_1 = 8.00, *SD* = 4.61; M_2 = 5.24, *SD* = 1.91). This suggests that earlier acquired items were less prone to error than later acquired items. Error/omission rates were also analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This revealed that there was no main effect of AoA on error/omission rates by-subject but there was a significant effect of AoA by-item which accounted for 18% of the variance; F_1 (1, 21) = 3.523, $p > .05$, partial $\eta^2 = .144$; F_2 (1, 33) = 7.404, $p = .01$, partial $\eta^2 = .183$. Therefore, while AoA did exert an effect in the by-item analysis of error/omission rates, this effect was not replicated in the by-subject analyses so must be interpreted with caution. This suggests that AoA exerted a significant, but partial effect on response accuracy in addition to the effect on response latencies.

6.4.4 Analysis of Total Fixation Durations

Table 6.2 reports the descriptive statistics for total fixation durations (ms) on earlier and later acquired items during picture naming. This suggested that participants fixated on earlier acquired items (M_1 = 602.40, *SD* = 221.78; M_2 = 616.90, *SD* = 61.57) for less time than they fixated on later acquired items (M_1 = 735.20, *SD* = 236.14; M_2 = 755.30, *SD* = 78.71).

Table 6.2 Average total fixation durations for experiment 4a

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Early acquired total fixation time	616.90 (61.57)	602.40 (221.78)
Late acquired total fixation time	755.30 (78.71)	735.20 (236.14)

Total fixation durations were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed a significant main effect of AoA on total fixation duration which accounted for 79% of the variance by-subject and 70% of the variance by-item, F_1 (1, 19) = 69.526, $p < .001$, partial $\eta^2 = .785$; F_2 (1, 33) = 75.377, $p < .001$, partial $\eta^2 = .696$. Therefore, participants fixated upon earlier acquired items for significantly less time than they fixated upon later acquired items. This implies that later acquired items required more effortful processing than earlier acquired items during picture naming. This suggests that AoA exerted a significant influence on perceptual processing in addition to indirect lexical access and articulation (as indicated by verbal response times).

6.5 Methodology for Experiment 4b

6.5.1 Design

Experiment 4b utilised a repeated measures design. Therefore, the independent variable was word frequency (high vs. low). The dependent variables were identical to those of Experiment 4a.

6.5.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 4b, participants consisted of 22 (5 males and 17 females) students and staff from the University of Worcester. Participants ranged from 18 to 42 years of age and with a mean age of 22.55 (6.77) years. However, total fixation duration data were only available for 20 participants due to movement during the experimental task.

6.5.3 Materials

The materials and word frequency stimuli sets for Experiment 4b were identical to those discussed in Chapter 2, Section 2.4.3.2.

6.5.4 Procedure

The procedure was identical to that used in Experiment 4a.

6.6 Results for Experiment 4b

6.6.1 Data Preparation

Data preparation processes were discussed in Chapter 2, Section 2.5.

6.6.2 Analysis of Response Times

Table 6.3 reports the descriptive statistics for average verbal response times (ms) to low and high frequency items during picture naming. This reveals that the verbal response times for low frequency items (M_1 = 690.52, *SD* = 116.23; M_2 = 686.39, *SD* = 70.97) were similar to those for high frequency items (M_1 = 691.70, *SD* = 101.03; M_2 = 690.89, *SD* = 60.97). This data suggested that there was little variation between the verbal response times for low and high frequency items.

To maintain consistency with the analyses performed in previous chapters, verbal response times for low and high frequency items were analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This revealed that there were no significant main effects of word frequency on verbal response times by-subject or by-item; F_1 (1, 21) = .023, $p > .05$, partial $\eta^2 = .001$; F_2 (1, 33) = .059, $p > .05$, partial $\eta^2 = .002$. Therefore, the verbal response times elicited by low frequency items were no slower than the verbal response times elicited by high-frequency items during picture naming. This suggests that word frequency did not exert an effect on indirect lexical access and articulation.

Table 6.3 Average response times and error/omission rates for Experiment 4b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency response time	686.39 (70.97)	690.52 (116.23)
High frequency response time	690.89 (60.97)	691.70 (101.36)
Low frequency error/omission rates	4.03 (2.56)	6.18 (5.24)
High frequency error/omission rates	3.26 (1.90)	5.05 (5.39)

6.6.3 Analysis of Error/Omission Rates

Table 6.3 also presents the average error/omission rates for low and high frequency items by-subject and by-item for picture naming. This reveals that error/omission rates were similar for low frequency items (M_1 = 6.18, *SD = 5.24*; M_2 = 4.03, *SD* = 2.56) and high frequency items (M_1 = 5.05, *SD* = 5.39; M_2 = 3.26, *SD* = 1.90).

Error/omission rates were analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This also revealed that there were no significant effects of word frequency on error/omission rates by-subject or by-item; F_1 (1, 21) = 2.754, $p > .05$, partial $\eta^2 = .116$; F_2 (1, 33) = 1.885, $p > .05$, partial $\eta^2 = .054$. Therefore, low frequency items were no more prone to error than high frequency items during picture naming and word frequency did not exert a significant effect on response accuracy.

6.6.4 Analysis of Total Fixation Durations

Table 6.4 reports the descriptive statistics for total fixation durations (ms) on low and high frequency items during picture naming. This suggests that total fixation durations were similar for low frequency items (M_1 = 627.16, *SD* = 158.59; M_2 = 640.10, *SD* = 91.49) and high frequency items (M_1 = 626.40, *SD* = 153.03; M_2 = 633.30, *SD* = 75.08).

Table 6.4 Average total fixation durations for Experiment 4b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency total fixation time	640.10 (91.49)	627.10 (158.59)
High frequency total fixation time	633.30 (75.08)	626 .40 (153.03)

Total fixation durations for low and high frequency items were analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This revealed that there were no main effects of word frequency by-subject or by item, F_1 (1, 19) = .004, $p > .05$, partial $\eta^2 = .001$; F_2 (1, 33) = .081, $p > .05$, partial $\eta^2 = .002$. This suggests that word frequency did not exert a significant effect on perceptual processing speed during picture naming.

6.7 Discussion of Results for Experiments 4a-4b

Chapter 6 has presented two semi-factorial experiments which investigated the effects of AoA and word frequency on verbal response times, error/omission rates and total fixation durations using an adaption of the picture naming task. The stimuli, procedure and sample were similar to those used in Experiments 1a – 3b and this facilitated comparison across the experimental paradigms in Chapter 9. The experiments reported in Chapter 6 also addressed several limitations of previous studies including the use of non-factorial designs and stimuli sets which were prone to the influence of confounding variables. Consequently, Chapter 6 has extended the findings reported in the previous experimental chapters and identified a potential locus of AoA during indirect lexical access and subsequent lexicalisation (Belke, Brysbaert, Meyer & Ghyselinck, 2005; Lambon Ralph & Ehsan, 2006). This is in addition to the potential loci already observed during perceptual-semantic processing. The implications for the hypotheses which were proposed for Experiment 4b are presented in Table 6.5.

Table 6.5 Implications for the hypotheses of Experiment 4a

Hypothesis	Evidence
Earlier acquired items will elicit significantly faster verbal responses than later acquired items.	Supported
Earlier acquired items will elicit significantly shorter total fixation durations than later acquired items.	Supported
Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items	Partially supported

This demonstrates that earlier acquired items were processed significantly faster than later acquired items. Furthermore, earlier acquired items were also fixated upon for significantly less time than later acquired items. The processing advantage for earlier acquired items in perceptual measures both supports and extends previous findings from studies which have combined other traditional experimental paradigms and eye-tracking. For example, Juhasz and Rayner (2006) documented similar AoA effects on eye-movements during word reading when target words were embedded in sentences. Interpreted in context of Juhasz and Rayner’s (2006) findings and the experiments reported in Chapters 3 - 5 of this thesis, this suggests that AoA exerts a significant influence on perceptual processing, semantic processing, indirect-lexical access, direct lexical access and articulation. However, sentence reading is a very complex process which is also tied to language proficiency, working memory, attentional control and comprehension. As a result, it is difficult to identify the loci of the AoA effects observed by Juhasz and Rayner (2006). Indeed, these effects have been a by-product of one of the other cognitive processes which were not assessed. Furthermore, Juhasz and

Rayner (2006) stimuli set consisted of just thirty-six target items embedded in sentences. This study orthogonally manipulated AoA and word frequency, meaning that there were eighteen earlier acquired items and eighteen later acquired items. This may explain why an affect was observed for word frequency. Indeed, it is a very small sample and a larger stimulus set is needed to reliably assess the effects of AoA and word frequency during lexicalisation. Therefore, while the experiments reported in Chapter 6 have provided an additional insight into the effects of AoA and word frequency on total fixation durations, further research is required to identify if similar effects are evident during single word reading. Indeed, the word reading paradigm is a significantly more controlled experimental task than sentence reading and a semi-factorial experimental design would produce a larger and more representative sample than that used by Juhasz and Rayner (2006).

The frequency-independent effects of AoA on verbal response times reported in this chapter supports previous studies which have investigated AoA effects during picture naming (Belke et al., 2005; Bodka et al., 2003; Bonin, Chalard, Méot & Fayol, 2002; Bonin, Fayol & Chalard, 2001; Lambon Ralph & Ehsan, 2006). It also lends support to the proposition that AoA exerts an effect during lexical-semantic encoding which involves arbitrary mapping between levels of representations in accordance with the connectionist model of AoA (Ellis & Lambon Ralph, 2000). Indeed, as identified in the introduction, picture naming presents a useful experimental technique for assessing AoA effects which arise between these levels of processing due to it requiring indirect lexical access via representations at lemma and lexeme levels (Jescheniak & Levelt, 1994; Kempen & Huijbers, 1983; Levelt, 1989). However, it is notable that several previous studies have documented smaller AoA effects in tasks which require direct lexical access and more transparent mappings between levels of processing, such as in the case of word reading in English (Belke et al., 2005; Lambon Ralph & Ehsan, 2006). This implies that further research is required to differentiate between the AoA and word frequency effects observed during these two routes to lexicalisation.

For example, Ellis, Burani, Izura, Bromiley and Venneri (2006) investigated the effects of AoA during covert object naming in which participants silently named items which were presented on the screen. This study also incorporated fMRI and presented interesting findings concerning the neural correlates of earlier acquired and later acquired items. When processing earlier acquired items participants showed greater activation in the occipital poles in the posterior region of the middle occipital gyri and in the left temporal lobe. This pattern of activation implies that earlier acquired items possess detailed visual and semantic representations and that these stimuli are highly interconnected at a neural level. In contrast, when processing later acquired items, participants displayed greater activation in the left middle occipital gyri and the fusiform gyri. These regions are associated with mapping visual information onto semantic information. Ellis et al. (2006) argued that this is the more difficult process and that it may account for why participants display a deficit when processing later acquired items. These findings lend further support for the multi-loci perspective of AoA effects and may explain the findings reported in this thesis. Furthermore, the findings reported by Ellis et al. (2006) were also supported by Urooj et al. (2014) who investigated the effects of AoA during covert picture naming while recording neural activity using Magnetoencephalography (MEG). The results reported in this study also suggested that earlier and later acquired items are processed differently at a semantic level which subsequently resulted in delayed visual responses. However, it remains unclear whether similar results would be observed during overt picture naming.

In regards to Experiment 4b, word frequency did not exert a significant effect on verbal response times, error/omission rates or total fixation durations when AoA, word length, imageability, visual complexity, familiarity, picture-name agreement and concreteness were controlled. The implications for the hypotheses which were proposed for Experiment 4b are presented in Table 6.6. This illustrates that the hypotheses were not supported.

Table 6.6 Implications for the hypotheses of Experiment 4b

Hypothesis	Evidence
High frequency items will elicit significantly faster verbal responses than low frequency items.	Not supported
High frequency items will elicit significantly shorter total fixation durations than low frequency items.	Not supported
High frequency items will elicit significantly fewer errors/omissions than low frequency items.	Not supported

The absence of significant effects of word frequency during picture naming supports Bonin, Fayol and Chalard (2001) but contradicts several studies which have observed word frequency effects in picture naming (Barry, Morrison & Ellis, 1997; Bodka et al., 2003; Bonin, Chalard, Méot & Fayol, 2002). However, these studies have employed non-factorial designs and regression analyses which reduce experimental control and statistical power respectively. Furthermore, when word frequency effects have been observed in picture naming, they are usually substantially smaller than those of AoA (Johnston & Barry, 2006). For example, Belke et al. (2005) observed that when AoA was entered into the stepwise regression first, it accounted for 56.4% of the variance in picture naming response times while word frequency only added .6% to the explained variance. When Belke et al. (2005) reversed this order, word frequency explained 22.8% of the variance which was increased to 57% when AoA was introduced to the model. However, it must be noted that in Belke et al.'s (2005) Experiment 2, AoA only explained .7% of the variance and word frequency increased this to 17%. This lends further support to the proposition that AoA effects may be lower in word reading than in picture naming and that word frequency may exert a stronger effect during this task. However, further research is required to identify if this is also observed when using a semi-factorial stimuli set.

Therefore, Chapter 7 reports two semi-factorial experiments which investigated the effects of AoA and word frequency on verbal response times, error/omission rates and total fixation durations during a word reading task. This experimental paradigm was chosen because it is a more controlled experimental task than sentence reading and because it enabled the researcher to investigate whether AoA and word frequency exerted significant effects during a task which relied on perceptual processing, direct lexical access, lexical retrieval and articulation. Indeed, unlike picture naming, a simple word reading task does not have a substantial semantic component due to the reliance on the direct route to lexicalisation via transparent spelling-to-sound mapping rather than via the semantic qualities of the stimuli (Bakhtiar & Weekes, 2014; Lambon Ralph & Ehsan, 2006). Therefore, by including both picture naming and word reading in this programme of research, the researcher was able to differentiate between effects between the direct and indirect routes to lexicalisation. To ensure results were comparable across experimental paradigms, the stimuli set, procedural elements and analytical processes are identical to those reported for Experiments 1a – 4b.

6.8 Chapter Conclusion

The findings reported in Chapter 6 have extended the finding reported in Chapters 3 - 5 by offering further support for the multi-loci perspective of AoA effects. Indeed, this chapter has enabled the researcher to identify significant AoA effects in a task which relies upon the arbitrary mapping between perceptual, semantic and lexical processing. Consistent with the multi-loci principles, this may have also been facilitated by the absence of word frequency effects due to the use of tightly controlled, semi-factorial, stimuli sets. Indeed, the patterns of results reported in Chapters 3 - 6 suggest that AoA exerts a significant but independent effect on perceptual processing, semantic processing, indirect-lexical access, retrieval and articulation. Furthermore, from the partial eta squared values reported in the experimental chapters, the strength of AoA effects have gradually increased with each additional experimental task. This lends support to arguments that AoA may have an accumulative effect (Catling & Johnston, 2009). However, AoA did not exert a consistent, significant effect on response accuracy during any of the experiments reported in this thesis so far despite its effects on response times. Several gaps in the literature and limitations of previous studies were also identified in Chapter 6 and these issues are subsequently addressed in Chapter 7. The following chapter extends on the findings reported in Chapters 3 - 6 by reporting two semi-factorial experiments which investigated the effects of AoA and word frequency during word reading. This enabled the researcher to explore the potential loci of these effects using a task which requires perceptual processing, direct lexical access, lexical retrieval and articulation. Furthermore, the delayed picture naming task reported in Chapter 8 also enabled the researcher to investigate whether the effects reported in

Chapters 6 and 7 were reducible to the onset of initial phoneme. The findings from this programme of research are subsequently compared and contrasted in Chapter 9.

Chapter 7: Immediate Word Reading

7.1 Chapter Overview

Chapter 7 reports two semi-factorial experiments which investigated the effects of AoA and word frequency on verbal response times, total fixation durations and error/omission rates during a word reading task when imageability, concreteness, picture-name agreement, category typicality, visual complexity, word length and familiarity were controlled. This experimental paradigm was chosen due to it extending the principles of the previous chapters and enabling the researcher to investigate potential loci of AoA and word frequency effects in a task requiring perceptual processing, semantic processing, direct lexical access, lexical retrieval and articulation. Furthermore, the use of methodological elements which were identical to those of the previous experiments enabled comparison across these studies. For example, the stimuli sets which were presented in Chapter 2 and used throughout this thesis were employed again during Experiments 5a and 5b but in textual format during an immediate word reading task. The sample was also derived from the same population and procedural elements such as display times were identical to those used in the previous experiments. This consistency across experimental paradigms also enabled the researcher to address several limitations of previous research, including the use of poorly controlled, non-factorial designs, unreliable stimuli sets and inconclusive analytical techniques.

The findings from Experiments 5a and 5b (immediate word reading) revealed similar patterns of results to those reported in previous chapters. These findings are subsequently interpreted with reference to theories and previous studies in the chapter discussion. Indeed, it is argued that the pattern of results is most consistent with the multi-loci perspective of AoA effects (Ellis & Lambon Ralph, 2000). For example, the results suggest that AoA effects are evident throughout the cognitive system and they are particularly prominent when word frequency does not exert an effect due to the researcher exercising control during the research design. It is also notable that the effects of AoA on immediate word reading were weaker than those observed during immediate picture naming (Experiment 4a). This is also consistent with the multi-loci perspective that AoA effects are most evident in tasks which involve arbitrary mapping between all levels of processing. Consequently, the AoA effect sizes observed across all of the experimental paradigms which were reported in this thesis are compared and contrasted in Chapter 9.

7.2 Introduction to Experiments 5a and 5b

Word reading is a useful and well established experimental paradigm in the AoA literature that enables researchers to examine the effects of AoA using a task which requires direct lexical access (Bakhtiar & Weekes, 2014; Brysbaert & Cortese 2011; Izura et al., 2011; Johnston & Barry, 2006; Juhasz & Rayner, 2006; Raman, 2011). For example, like picture naming, word reading utilises perceptual processing. However, unlike picture naming which relies on the indirect route to lexicalisation via semantic properties, word reading in English relies on the direct route to lexicalisation which bypasses semantic processing (Bakhtiar & Weekes, 2014; Ellis & Morrison, 2000; Johnston & Barry, 2006). This is because languages with regular orthographies can be characterised by relatively transparent spelling-to-sound mapping, which means participants do not need to access semantic information to retrieve information from the mental lexicon (Chen, Zhou, Dunlap & Perfitti, 2007; Lambon Ralph & Ehsan, 2006).

Therefore, word reading is an appropriate experimental paradigm the purposes of this chapter. However, it must be noted that although semantic access is not required for successful word reading, this does not completely exclude the possibility that participants would engage in some degree of conceptual processing (Ellis et al., 2006; Lewis, 2006; Rayner, Chace, Slattery & Ashby, 2006).

Previous research has suggested that AoA effects frequently emerge during word reading but these effects are usually smaller in magnitude than those observed during pictorial tasks (Belke, Brysbaert, Meyer & Ghyselinck, 2005; Brysbaert & Ghyselinck, 2006). For example, Lambon Ralph and Ehsan (2006) identified a large AoA effects in picture naming which they were not able to replicate when using the same object labels during word reading after word frequency, visual complexity, name agreement and word length were controlled. This is consistent with the multi-loci perspectives principle that AoA effects will be most evident when the mapping between the presented stimuli, cognitive processes and the required response are arbitrary (Catling, Johnston, Preece & Dent, 2013; Chen, Zhou, Dunlap & Perfetti, 2007; Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008). Indeed, Chen, Zhou, Dunlop and Perfetti (2007) investigated the effects of AoA during the reading of Chinese characters which varied in predictability. They identified that AoA effects were strongest when the mapping between the item presented and response was unpredictable. Although the findings from this study may not be generalizable to word reading in English due to differences in orthographic properties, it does lend further support to the multi-loci perspective of AoA effects (Catling, Johnston, Preece & Dent, 2013; Chen, Zhou, Dunlap & Perfetti, 2007; Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008).

However, it must be noted that Lambon Ralph and Ehsan (2006) also identified significant word frequency effects during word reading and it is important to remember that multi-loci perspective predicts weaker AoA effects when there is a co-occurring effect of word frequency (Ellis & Lambon Ralph, 2000). As outlined in Chapter 1, Section 1.2., Brysbaert and Ghyselinck (2006) identified that frequency-related AoA effects are most evident in tasks involving word reading. This suggests that word frequency may have confounded these findings and masked significant effects of AoA. However, Cortese and Khanna (2007) identified that AoA was the most prominent predictor of response times during word reading even after twenty-two other psycholinguistic properties (including word frequency) were controlled. Although these properties were controlled during the analyses and not during experimental design, it does suggest that greater control over the stimuli sets may be beneficial for detecting valid and reliable AoA effects during word reading tasks. Consequently, the same semi-factorials stimuli sets which were outlined in Chapter 2 and used throughout this thesis were also used during Experiments 5a and 5b.

It is also notable that Juhasz and Rayner (2006) have previously documented significant effects of AoA, word frequency, familiarity, word length and concreteness on eye-movements during covert (e.g. silent) sentence reading. However, as noted in Chapter 6, Section 6.7, sentence reading is a very complicated experimental paradigm that involves the application of a wide variety of processes which are performed simultaneously (Rayner, 1998; Rayner, Chase, Slattery & Ashby, 2006; Rayner & Juhasz, 2004; Roelofs, 2007). This includes word recognition, comprehension, logic, attention and memory. Indeed, although comprehension was checked on 10-15% of trials in Juhasz and Rayner's (2006) study, it is not possible to guarantee that participants read and understood every item. For example, individuals who are competent readers tend to automatically skip entire words or segments of words which are anticipated in order to maximise reading speed (Rayner, 1998; Roelofs, 2007). Furthermore, while Juhasz and Rayner (2006) identified that fixating on a stimulus tends to reflect processing other words may be present in peripheral vision. This suggests that fixations may reflect the processing of other words in the visual field if stimuli are presented in sentence format. It is also notable that inhibition of return can confound results if participants shift their gaze to another item and are unable to quickly return their gaze to the previously attended item even if this item was not initially understood (Rayner, 1998; Rayner, Chase, Slattery & Ashby, 2006; Roelofs, 2007). Therefore, while Juhasz and Rayner's (2006) study provided valuable insights into AoA effects during reading, further research is required to assess the effects of AoA on eye-movements using a more controlled experimental design. Hence, Experiments 5a and 5b assessed the effects of AoA and word frequency on word reading. These words were presented in isolation and a verbal response was required to ensure participants read, processed and understood each item.

Therefore, Chapter 7 presents two semi-factorial experiments which investigated the effects of AoA and word frequency on verbal response times, error/omission rates and total fixation durations using an adaptation of the word reading experimental paradigm. To address the limitations of previous studies, stimuli characteristics were controlled during the research design, words were presented individually, the effects of AoA and word frequency were considered separately and the results were also analysed by-subject and by-item using two separate repeated measures analysis of variance. This experimental paradigm was chosen due to it enabling the researcher to investigate the potential loci of AoA and word frequency effects during perceptual processing, direct lexical access, lexical retrieval and articulation. Interpreted in the context of the previous experimental chapters, Chapter 7 was also designed to identify if AoA and word frequency effects are stronger or weaker during tasks which require direct lexical access as opposed to indirect lexical access.

7.2.1 Hypotheses for Experiment 5a

Three hypotheses were formulated for Experiment 5a based on the insights provided by the literature reported in Chapter 1:

- Earlier acquired items will elicit significantly faster verbal responses than later acquired items.
- Earlier acquired items will elicit significantly shorter total fixation durations than later acquired items.
- Earlier acquired items will elicit significantly fewer errors/omissions than later acquired items.

7.2.2 Hypotheses for Experiment 5b

Three hypotheses were also formulated for Experiment 5b based on the literature reported in Chapter 1:

- High frequency items will elicit significantly faster verbal response times than low frequency items.
- High frequency items will elicit significantly shorter total fixation durations than low frequency items.
- High frequency items will elicit significantly fewer errors/omissions than low frequency items.

7.3 Methodology for Experiment 5a

7.3.1 Design

Experiment 5a utilised a repeated measures design. The independent variable was AoA (early vs. late acquired). The first dependent variable was verbal response times (ms). This was operationalised as the difference between the time at which the critical item was presented on the screen and the onset of a verbal response as recorded by a microphone. The second dependent variable was error/omission rate as operationalised as the total number of times the participants provided an incorrect answer, failed to produce a response while the critical item remained on the screen or produced a response which was beyond two standard deviations from the mean. The final dependent variable was the total fixation duration (ms). This was operationalised as the total amount of time participants spent looking directly at the critical item while it remained on the screen regardless of the number of times participants shifted their gaze during the trial.

7.3.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 5a, participants consisted of 22 (6 males and 16 females) students and staff from the University of Worcester. Participants ranged from 18 to 47 years of age, with a mean age of 23.59 (7.79).

7.3.3 Materials

The materials and AoA stimuli sets for Experiment 5a were identical to those discussed in Chapter 2, Section 2.4.3.1. Therefore, the AoA stimuli set consisted of Morrison, Chappell, and Ellis' (1997) names for the objects used in Experiments 1a (Chapter 3), 2a (Chapter 4), 3a (Chapter 5) and 4a (Chapter 6).

6.3.4 Procedure

The calibration of the eye-tracking equipment was described in Chapter 2, Section 2.4.5. After the calibration was complete, participants were instructed to limit their bodily movement and speak clearly throughout the experiment before pressing the spacebar to proceed to the standardised written instructions. When participants understood these instructions they were instructed to press the space bar to complete 6 practice trials. The 68 critical trials followed automatically. For each trial participants viewed a fixation cross in the centre of the screen for 2000ms. The target word was then presented in the centre of the screen for 1500ms and participants were required to say the word while it remained on the screen by speaking clearly into the microphone. The items were always presented in black, bold, Times New Roman font size 48. The experimenter recorded errors manually. No immediate feedback was provided after the trials although there was an inter-trial interval of 2000ms which begun at the detection of a verbal response. The order of critical trials was randomised to reduce order, practice and boredom effects. After completing the experiments participants were provided with a verbal and standardised written debriefing. Figure 7.1 presents screenshots of the calibration grid, critical trials and debriefing for the word reading experiment. A trial consisted of the third, fourth and fifth screenshot.

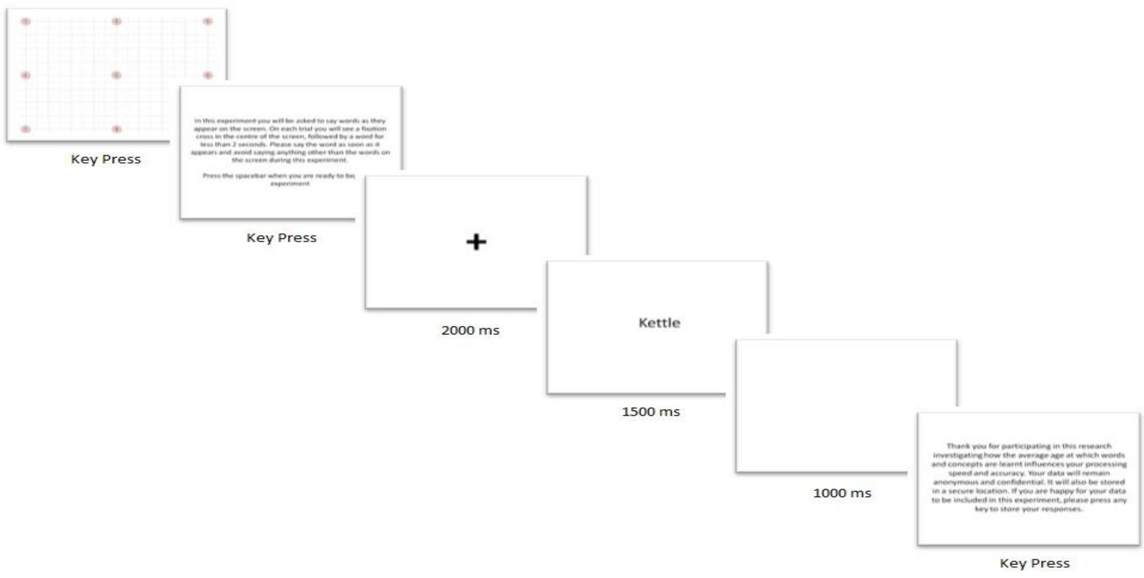

Figure 7.1 The procedure for word reading tasks

7.4. Results for Experiment 5a

7.4.1 Data Preparation

Data preparation processes were discussed in Chapter 2, Section 2.5.

7.4.2 Analysis of Response Times

Table 7.1 presents the descriptive statistics for average verbal response times for earlier and later acquired words by-subject and by-item. This demonstrates that earlier acquired words (M_1 = 481.81, *SD* = 54.58; M_2 = 476.64, *SD* = 23.29) were read faster than later acquired words (M_1 = 534.51, *SD* = 73.37; M_2 = 533.33, *SD* = 21.24). Consequently, to maintain consistency with the analyses performed in previous chapters, verbal response times for earlier and later acquired items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed significant a main effect of AoA on verbal response times by-subject and by-item which accounted for 56% and 76% of the variance respectively; F_1 (1, 21) = 26.657, $p < .001$, partial $\eta^2 = .559$; F_2 (1, 33) = 106.682, $p < .001$, partial $\eta^2 = .764$. Therefore, earlier acquired words were named significantly faster than later acquired words. This suggests that AoA exerted a significant effect during direct lexical access and subsequent articulation.

Table 7.1 Average response times and error/omission rates for Experiment 5a

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Early acquired response time	476.64 (23.29)	481.81 (54.58)
Late acquired response time	533.33 (21.24)	534.51 (73.37)
Early acquired error/omission rates	3.29 (1.59)	5.00 (5.66)
Late acquired error/omission rates	3.77 (1.63)	5.91 (4.49)

7.4.3 Analysis of Error/Omission Rates

Table 7.1 also presents the average error/omission rates for earlier and later acquired words by-subject and by-item. This suggests that earlier acquired items (M_1 = 5.00, SD = 5.66; M_2 = 3.29, SD = 1.59) produced slightly fewer errors/omissions than later acquired items (M_1 = 5.91, SD = 4.49; M_2 = 3.77, SD = 1.63). Consequently, error/omission rates for earlier acquired and later acquired items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed that there was no significant effect of AoA on errors/omissions by-subject or by-item; F_1 (1, 21) = .550, $p > .05$, partial $\eta^2 = .026$; F_2 (1, 33) = 1.493, $p > .05$, partial $\eta^2 = .043$. Despite the initial trend for fewer errors to be produced when processing earlier acquired words compared to when participants processed later acquired words, this difference was statistically significant. Therefore, AoA did not exert a significant effect on response accuracy during word reading despite its influence on response latencies.

7.4.4. Analysis of Total Fixation Durations

Table 7.2 reports the descriptive statistics for total fixation durations (ms) on earlier and later acquired words during the word reading task. This suggests that participants fixated on earlier acquired words (M_1 = 462.60, *SD* = 103.23; M_2 = 456.50, *SD* = 26.75) for less time than they fixated on later acquired words (M_1 = 528.50, *SD* = 143.66; M_2 = 540.30, *SD* = 53.82).

Total fixation durations for earlier and later acquired items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed that there was a significant main effect of AoA on total fixation durations by-subject and by-item which accounted for 50% and 68% of the variance respectively, F_1 (1, 21) = 21.047, $p < .001$, partial $\eta^2 = .501$; F_2 (1, 33) = 69.732, $p < .001$, partial $\eta^2 = .679$. Therefore, earlier acquired items were fixated upon for significantly less time than later acquired items, implying faster perceptual processing for earlier acquired items than later acquired items. This indicated that AoA exerted a significant effect on perceptual processing speed during word reading.

Table 7.2 Average total fixation durations for Experiment 5a

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Early acquired total fixation time	456.50 (26.75)	462.60 (103.23)
Late acquired total fixation time	540.30 (53.82)	528.50 (143.66)

7.5 Methodology for Experiment 5b

7.5.1 Design

Experiments 5b also employed a repeated measures design similar to the design used in Experiment 5a. However, the independent variable for Experiment 5b was word frequency (low frequency vs. high frequency). The dependent variables were identical to those reported for Experiment 5a.

7.5.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 5b, data were collected from 22 (2 males and 20 females) students and staff from the University of Worcester. Participants ranged from 19 to 57 years of age, with a mean age of 34.14 (10.80).

7.5.3 Materials

The materials and word frequency stimuli sets for Experiment 5b were identical to those discussed in Chapter 2, Section 2.4.3.2. Therefore, the word frequency stimuli set consisted of Morrison, Chappell, and Ellis' (1997) names for the objects used in Experiments 1b (Chapter 3), 2b (Chapter 4), 3b (Chapter 5) and 4b (Chapter 6).

7.5.4 Procedure

The procedure was identical to that used in Experiment 5a.

7.6 Results for Experiment 5b

7.6.1 Data Preparation

Data preparation processes were discussed in Chapter 2, Section 2.5.

7.6.2 Analysis of Response Times

Table 7.3 presents the descriptive statistics for verbal response times to low and high frequency items by-subject and by-item. This suggests that verbal response times were similar for low frequency words (M_1 = 501.61, *SD* = 66.50; M_2 = 501.13, *SD* =

19.47) and high frequency words (M_1 = 500.52, *SD* = 59.17; M_2 = 500.58, *SD* = 25.22). Therefore, there may not be a significant effect of word frequency on verbal response times during the word reading task.

Table 7.3 Average response times and error/omission rates for Experiment 5b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency response time	501.13 (19.47)	501.61 (66.50)
High frequency response time	500.58 (25.22)	500.52 (59.17)
Low frequency error/omission rates	1.09 (.98)	1.64 (1.09)
High frequency error/omission rates	1.21 (.98)	1.91 (1.93)

To maintain consistency with the analyses performed in previous chapters, verbal response times for low and high frequency words were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed that there were no significant main effects of word frequency on verbal response times by-subject or by-item; F_1 (1, 21) = .042, $p > .05$, partial $\eta^2 = .002$; F_2 (1, 33) = .009, $p > .05$, partial $\eta^2 = .001$. This suggests that there was little variation between the verbal response times for low and high frequency items. Therefore, word frequency did not exert a significant effect on the speed of direct lexical access and subsequent articulation.

7.2.3 Analysis of Error/Omission Rates

Table 7.3 also reports the average error/omission rates for low and high frequency words by-subject and by-item for the word reading task. This demonstrates that there the error/omission rate for low frequency words (M_1 = 1.64, *SD* = 1.09; M_2 =

1.09, *SD* = .98) was similar to the error/omission rate for high frequency words (M_1 = 1.91, *SD* = 1.93; M_2 = 1.21, *SD* = .98).

Error/omission rates for low and high frequency words were also analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed that there was no significant main effect of word frequency on the number of errors/omissions produced by-subject or by-item; F_1 (1, 21) = .551, $p > .05$, partial η^2 = .026; F_2 (1, 33) = .237, $p > .05$, partial η^2 = .007. Therefore, low frequency words were no more prone to error than high frequency words. This suggests that word frequency did not influence response accuracy during word reading.

7.2.4 Analysis of Total Fixation Durations

Table 7.4 reports the descriptive statistics for total fixation durations (ms) for Experiment 5b. This suggested that total fixation durations were similar for low frequency words (M_1 = 459.00, *SD* = 245.01; M_2 = 471.90, *SD* = 29.17) and high frequency words (M_1 = 463.80, *SD* = 245.34; M_2 = 474.20, *SD* = 35.17).

Table 7.4 Average total fixation durations for Experiment 5b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency total fixation time	471.90 (29.17)	459.00 (245.01)
High frequency total fixation time	474.20 (35.17)	463.80 (245.34)

Total fixation durations for low and high frequency items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed that there was no significant main effect of word frequency on total fixation durations by-subject or by-item, F_1 (1, 21) = .494, $p > .05$, partial $\eta^2 = .023$; F_2 (1, 33) = .094, $p < .05$, partial $\eta^2 = .003$. Therefore, participants did not fixate on low frequency items for more time than they fixed on high frequency items. This indicates that word frequency did not exert a significant influence on perceptual processing time during word reading.

7.7 Discussion of Results for Experiments 5a-5b

Chapter 7 reported two semi-factorial experiments which investigated the effects of AoA and word frequency on verbal response times, error/omission rates and total fixation durations during the word reading experimental paradigm. This expanded on the findings reported in Chapters 3 – 6 by assessing AoA and word frequency effects during a task which required perceptual processing, direct lexical access, lexical retrieval and articulation (Chen, Zhou, Dunlop & Perfetti, 2007; Cortese & Khanna, 2007; Johnston & Barry, 2006). Indeed, object recognition (Chapter 3) relies on perceptual processing while picture-category verification/falsification (Chapter 4) relies on perceptual processing and semantic processing. Furthermore, picture-name verification/falsification (Chapter 5) relies on perceptual processing, semantic processing and indirect lexical access without the requirement of articulation. In contrast to these paradigms, picture naming (Chapter 6) relies on perceptual processing, semantic processing, indirect lexical access and articulation. The choice of experimental tasks subsequently enabled the researcher to examine the potential AoA and word frequency effects across the cognitive system.

The primary findings from Experiment 5a were that AoA did exert a significant effect on verbal response times and total fixation durations during word reading. However, in accordance with the previous experiments, AoA did not exert a significant effect on response accuracy. Therefore, the implications for the hypotheses which were proposed for Experiment 5a are presented in Table 7.5. This demonstrates that two of the three hypotheses were supported. Indeed, the faster verbal responses for earlier acquired items than later acquired items suggest that AoA exerts a significant influence on direct lexical access, lexical retrieval and articulation. Furthermore, the significant effect of AoA on total fixation duration also suggests that the processing advantage for earlier acquired items begins during perceptual processing (Juhasz & Rayner, 2004; Roelofs, 2007; Yee & Sedivy, 2006).

Table 7.5 Implications for the hypotheses of Experiment 5a

Hypothesis	Evidence
Earlier acquired items will elicit significantly faster verbal responses than later acquired items.	Supported
Earlier acquired items will elicit significantly shorter total fixation durations than later acquired items.	Supported
Earlier acquired items will elicit significantly fewer errors and omissions than later acquired items.	Not supported

The pattern of results reported in this thesis is most consistent with the multi-loci perspective of AoA effects as outlined in Chapter 1, Section 1.2.3. Indeed, using the partial eta squared values, it can be seen that the effects of AoA stronger during picture naming than during word reading. This is consistent with the multi-loci perspective that

AoA effects will be most pronounced during experimental tasks which are characterised by arbitrary mapping between the presented stimuli, levels of representation and the required response (Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008). Indeed, as outlined in the Chapter 7, Section 7.2, word reading can be characterised by more transparent mapping due to the reliance on spelling-to-sound correspondence (Catling, Johnston, Preece & Dent, 2013; Chen, Zhou, Dunlap & Perfetti, 2007; Ellis & Lambon Ralph, 2000; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008). These findings are also consistent with a number of previous studies which have reported lower AoA effects in word reading than those reported in picture naming (Belke, Brysbaert, Meyer & Ghyselinck, 2005; Lambon Ralph & Ehsan, 2006). However, a full analysis and comparison of the effect sizes observed during the experiments reported in this thesis is presented in Chapter 9. Therefore, this implies that the dissociation between the effects of AoA on direct and indirect lexical access is a valid and reliable finding

The primary findings from Experiment 5b were that word frequency did not exert a significant effect on verbal response times, error/omission rates or total fixation durations during word reading. Therefore, the implications for the hypotheses for Experiment 5b are presented in Table 7.6. These findings contradict Lambon Ralph and Ehsan (2006), who argued that the effects of word frequency during word reading superseded those of AoA. However, it must be noted that while Lambon Ralph and Ehsan (2006) observed a slight advantage for later acquired items during word reading, this trend was not statistically significant. They also observed an interaction between AoA and word frequency, which suggested that later acquired items were differentially impaired by low word frequency. However, again this trend was not statistically significant.

Table 7.6 Implications for the hypotheses of Experiment 5b

Hypothesis	Evidence
High frequency items will elicit significantly faster verbal response times than low frequency items.	Not supported
High frequency items will elicit significantly shorter total fixation durations than low frequency items.	Not supported
High frequency items will elicit significantly fewer errors and omissions than low frequency items.	Not supported

The differences between the current Experiment 5b and the results reported by Lambon Ralph and Ehsan (2006) may be explained by differences between the stimuli sets. For example, although the stimuli used in Lambon Ralph and Ehsan's (2006) study and the current Experiment 5b both utilised normative data derived from Morrison et al., (1997), Lambon Ralph and Ehsan only drew on one measure of AoA, one measure of word frequency, visual complexity, name agreement and letter length. In contrast, the stimuli sets used throughout this thesis were created using four measures of AoA, two measures of word frequency, picture-name agreement, category typicality, familiarity, imageability, concreteness, visual complexity and three measures of word length. Therefore, the stimuli sets which were used in this thesis were more rigorously controlled than those used by Lambon Ralph and Ehsan (2006). This may have ensured that the stimuli sets used in the current research were more valid and reliable than those used in some of the previous studies.

It is also notable that Experiment 5a supports and extends the findings presented by Juhasz and Rayner (2006). Indeed, AoA did exert a significant effect on total fixation durations in a word reading task despite these items being presented in isolation rather than in sentence format. However, Experiment 5b did not replicate the effects of word frequency which were observed by Juhasz and Rayner (2006). This may be explained by the differences between the stimuli sets used during this programme of research and those used by Juhasz and Rayner (2006). Indeed, while the experiments reported in this thesis employed semi-factorial designs to ensure stimuli sets were valid and reliable, Juhasz and Rayner (2006) employed a fully factorial design. This meant that each set only consisted of 9 items as opposed to the studies reported in this thesis which included 34 items per set (e.g. 34 low frequency items and 34 high frequency items). A small stimulus set may not be representative of the mental lexicon and it is also sensitive to the confounding influence of other item psycholinguistic properties (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Therefore, the larger stimuli set employed in the current research may have enabled the researcher to successfully detect dissociated AoA and word frequency effects during word reading.

Based on the findings reported in this chapter, AoA did exert a significant, valid and reliable effect on verbal response times and total fixation durations during word reading. These effects were independent of word frequency, which did not exert a significant effect during this task. Interpreted in the context of the previous chapters, it can be argued that AoA effects permeate throughout the cognitive system. However, as discussed in Chapter 2, Section 2.2.6, initial phoneme was not controlled during the design of the stimuli sets or during the statistical analyses despite this variables potential influence on verbal response times (Catling & Johnston, 2005, 2009; Holmes & Ellis, 2006; Morrison & Ellis, 2000). Therefore, Chapter 8 reports two semi-factorial experiments which investigated the effects of AoA and word frequency during a delayed picture naming task. To identify the potential locus or loci of AoA and word frequency effects, Chapter 9 subsequently presents a comparison of the effect sizes observed across all of the experimental paradigms reported in this thesis.

7.8 Chapter Conclusion

Chapter 7 reported two semi-factorial experiments which investigated the effects of AoA and word frequency during an adaptation of the word reading experimental paradigm. These experiments revealed that AoA exerted a significant effect on verbal response times and total fixation durations but word frequency did not. This suggests that AoA exerts a significant influence on perceptual processing, direct lexical access, lexical retrieval and articulation. Furthermore, interpreted in context the experiments reported in this thesis suggest that AoA effects permeate throughout the cognitive system while word frequency has very little influence on processing speed or response accuracy. However, initial phoneme was not controlled during the design of the stimuli sets which were used throughout this thesis. This suggests that difficulties in initiating articulation may have confounded verbal response times. Consequently, Chapter 8 reports two semi-factorial experiments which investigated if the results presented in Chapter 6 and Chapter 7 may have been confounded by initial phoneme using a delayed picture naming experimental paradigm.

Chapter 8: Delayed Picture Naming

8.1 Chapter Overview

Chapter 6 (Immediate Picture Naming) and Chapter 7 (Immediate Word Reading) reported significant effects of AoA, but no consistent significant effects of word frequency, during a task which required verbal responses. The significant effects of AoA during immediate picture naming suggested that AoA may exert a significant effect on tasks which rely on the indirect route to lexicalisation via the semantic properties of the stimuli (Bakhtiar & Weekes, 2014; Catling & Johnston, 2009; Ellis & Morrison, 1998; Holmes & Ellis, 2006; Lambon Ralph & Ehsan, 2006). In contrast, the significant effects of AoA during immediate word reading suggested that AoA can also influence performance during a task which relies on the direct route to lexicalisation via the orthographic properties of the same stimuli (Barry, Hirsh, Johnston & Williams, 2001; Catling & Johnston, 2005; Garlock, Walley & Metsala, 2001; Gerhand & Barry, 1998; Moore, Smith-Spark & Valentine, 2004). A full comparison of effect sizes is reported in Chapter 9, although an initial inspection of the effect sizes reported in Chapter 6 and Chapter 7 suggested that the effects of AoA were more prominent during immediate picture naming than during immediate word reading. These findings expanded on the results reported in the previous chapters by differentiating between the AoA effects elicited by two alternative routes to lexicalisation and subsequently identified significant effects of AoA on lexical processing.

However, these results may also reflect difficulties in the process of initiating articulation (Catling & Johnston, 2005, 2009; Ellis & Morrison, 1998; Morrison & Ellis, 1995, 2000). Indeed, initial phoneme was not controlled during the design of the stimuli sets used throughout this thesis. Therefore, Chapter 8 reports two semi-factorial delayed picture naming experiments which investigated whether the verbal response times reported in this thesis may have been confounded by the onset of initial phoneme. These experiments revealed that there were no significant effects of AoA or word frequency during delayed picture naming, which implies that difficulties in initiating articulation did not confound the results reported in Chapter 6 or Chapter 7.

8.2 Introduction to Experiments 6a and 6b

The delayed picture naming paradigm was included in this programme of research due to it enabling the investigation of whether the effects reported in Chapter 6 (Immediate Picture Naming) and Chapter 7 (Immediate Word Reading) could have been confounded by difficulties in initiating articulation (Catling & Johnston, 2009; Ghyselinck, Lewis & Brysbaert, 2004; Holmes & Ellis, 2006; Morrison & Ellis, 1995, 2000). Indeed, significant effects during a delayed naming paradigm would suggest that initial phoneme may have confounded the verbal response times reported in the previous chapters. For example, this would suggest that the stimuli set which elicited the shorter average response time consisted of items which began with initial phonemes which were easier to articulate than those of the set which elicited the longer response times (Catling & Johnston, 2009; Ghyselinck, Lewis & Brysbaert, 2004; Holmes & Ellis, 2006; Morrison & Ellis, 1995, 2000).

However, previous studies have frequently reported inconsistent results for delayed naming conditions. Indeed, Ghyselinck, Lewis and Brysbaert (2004) reported significant effects of AoA during immediate and speeded word reading but not during delayed word reading. In contrast, significant effects of word frequency were observed during speeded word reading and delayed word reading but not during immediate word reading. These findings suggest that the stimuli set which manipulated word frequency was more susceptible to difficulties in initiating articulation than the stimuli set which manipulated AoA. Navarrete et al. (2013) also investigated the effects of AoA during delayed picture naming while word frequency was controlled. In this study, 25% of trials involved delayed naming while 75% of trials involved a gender discrimination task. In contrast to Ghyselinck, Lewis and Brysbaert's (2004) findings, Navarrete at al. (2012) reported significant effects of AoA during delayed picture naming which suggests that AoA stimuli sets may also be susceptible to the effects of initial phoneme. However, it should be noted that these results were not interpreted in context due to the absence of immediate or speeded naming condition. Furthermore, the results were derived from a very small sample of ten earlier acquired items and ten later acquired items. Therefore, in addition to possibly reflecting confounding effects of initial phoneme, these results may also reflect sampling bias (Lewis, 2006; Zevin & Seidenberg, 2002, 2004).

Despite these findings, it is notable that most studies which have incorporated delayed word reading or picture naming have not detected significant effects of AoA or word frequency. This suggests that the majority of stimuli sets used in AoA research are not susceptible to the influences of initial phoneme. For example, Catling and Johnston (2005) and Morrison and Ellis (1995) observed significant effects of AoA during immediate word reading but not during delayed word reading, while there were no significant effects of word frequency during immediate or delayed word reading. Furthermore, while Gerhand and Barry (1998) reported significant effects of both AoA and word frequency during immediate word reading, there were no significant effects of

AoA or word frequency during delayed word reading. Catling and Johnston (2009), Ellis and Morrison (1998) and Holmes and Ellis (2006) also detected significant effects of AoA during immediate picture naming but not during delayed picture naming. However, it must be noted that although the delays between presentation and cued response were relatively short at 100ms and 500msm only Morrison and Ellis (1995) incorporated more than one timescale for the delay. Indeed, all of the other studies reported in this chapter only incorporated one time period for the delay between presentation and cued response. This implies that some degree of predictability was still present in each of these studies and that the results may still have been confounded by difficulties in initiating articulation. Furthermore, it is also notable that the delays incorporated in the studies reported in this chapter ranged from 100ms – 2800 ms but only Ellis and Morrison (1998) presented a rationale for their choice of delay. Indeed, this was based on the longest response time observed during immediate picture naming. However, this was the only delay used by Ellis and Morrison (1998), which suggests that the onset of articulation retained some degree of predictable. This demonstrates that results obtained across these studies may not be comparable due to methodological differences.

Therefore, while few studies have detected significant effects of AoA or word frequency during delayed picture naming or delayed word naming, predictability of cued responses during delayed naming conditions may mask significant effects of initial phoneme. This suggests that further methodological adaptation is required to investigate whether effects of AoA and word frequency on verbal response times are susceptible to the influence of initial phoneme. This is particularly salient for this programme of research because all of the experiments reported in this thesis utilised new, semi-factorial stimuli sets in which initial phoneme was not controlled. Hence, further research was required to investigate whether the the stimuli sets used in this programme of research were confounded by difficulties in initiating articulation. Chapter 8 reports two semi-factorial experiments which utilised an adaptation of the delayed picture naming experimental paradigm. To address the limitation of previous research, these studies incorporated variable delays of 1200ms (the longest response time observed during immediate picture naming), 1600ms and 2000ms. Furthermore, to facilitate comparison between delayed picture naming and the experimental paradigms reported in Chapters 3 – 7, all of the other methodological elements detailed in Chapter 2 were held as constant during delayed picture naming.

8.2.1 Hypotheses for Experiment 6a

The hypotheses which were formulated for Experiment 6a are presented below:

- If the results reported in Chapter 6 and Chapter 7 were confounded by initial phoneme, earlier acquired items will elicit significantly shorter response times than those observed for later acquired items during delayed picture naming conditions.
- Later acquired items will elicit significant more errors/omissions than earlier acquired items.

8.2.2 Hypotheses for Experiment 6b

The hypotheses which were formulated for Experiment 6b are presented below:

- If the results reported in Chapter 6 and Chapter 7 were confounded by initial phoneme, high frequency items will elicit significantly shorter response times than those observed for low frequency items during delayed picture naming conditions.
- Low frequency items will elicit significant more errors/omissions than high frequency items.

8.3 Methodology for Experiment 6a

8.3.1 Design

Experiment 6a utilised a repeated measures design. Therefore, the independent variable was AoA (early vs. late acquired). The first dependent variable was verbal response times (ms). This was operationalised as the difference between when the cue was presented and the onset of a verbal response. The second dependent variable was error/omission rate as operationalised as the total number of times the participants provided an incorrect answer, failed to produce a response while the critical item remained on the screen or produced a response which was beyond two standard deviations from the mean.

8.3.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 6a, participants consisted of 20 (3 males and 17 females) undergraduate and postgraduate students. Participants ranged from 18 to 31 years of age with a mean age of 21.55 (4.59) years.

8.3.3 Materials

The materials were identical to those discussed in Chapter 2, Section 2.4.3.1.

8.3.4 Procedure

The procedure was identical to the procedure used during Experiment 4a with the exception of a delay between the presentation of each object and the corresponded cued response. Therefore, for each of the randomly ordered critical trials participants viewed a fixation cross in the centre of the screen for 2000ms. The target item was then presented in the centre of the screen for 1500ms and this was followed by a randomised delay of 1200ms, 1600ms or 2000ms. Participants were then cued to name the object by the word ‘Name?’ which remained on the screen until a response was detected. This was followed by an inter-trial interval of 2000ms before the next fixation cross was presented. Therefore, the response times recorded by E-Prime reflected the difference between when the cue was presented and when a response was detected. The experimenter recorded errors or omissions manually. After completing the experiments participants were provided with a verbal and standardised written debriefing.

8.4 Results for Experiment 6a

6.4.1 Data Preparation

Data preparation procedures were discussed in Chapter 2, Section 2.5.

8.4.2 Analysis of Response Times

Table 8.1 presents the descriptive statistics for average verbal response times (ms) produced for earlier and later acquired items during picture naming. This demonstrates that there was little variation between the response times for earlier acquired items (M_1 = 481.66, *SD* = 119.40; M_2 = 473.55, *SD* = 35.93) and the response times to later acquired items (M_1 = 478.56, *SD* = 123.07; M_2 = 474.04, *SD* = 41.91) during delayed naming.

However, to maintain consistency with the analyses performed in the previous chapters, verbal response times for earlier and later acquired items were analysed by-subject and by-item using two separate repeated measures analyses of variance. This revealed that there were no significant main effects of AoA on verbal response times by-subject and by-item during delayed naming; F_1 (1, 19) = .169, p = .686, partial η^2 = .009; F_2 (1, 33) = .002, p = .961, partial η^2 = .001. This suggests that the effects which were attributed to AoA in Experiment 4a and Experiment 5a were not confounded by the effects of initial phoneme.

Table 8.1 Average response times and error/omission rates for Experiment 6a

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Early acquired response time	473.54 (35.93)	481.66 (119.40)
Late acquired response time	474.04 (41.91)	478.56 (123.07)
Early acquired errors/omissions	2.06 (1.67)	3.55 (3.98)
Late acquired errors/omissions	2.18 (1.57)	3.80 (4.26)

8.4.3 Analysis of Error/Omission Rates

Table 8.1 also presents the descriptive statistics for average error/omission rates produced for earlier and later acquired items during delayed picture naming. This demonstrates that error/omission rates for earlier acquired items (M_1 = 3.55, *SD* = 3.98; M_2 = 2.06, *SD* = 1.67) were similar to those for later acquired items (M_1 = 3.80, *SD* = 4.26; M_2 = 2.18, *SD* = 1.57). Error/omission rates were also analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This revealed that there were no main effects of AoA on error/omission rates by-subject or by-item during delayed picture naming; F_1 (1, 19) = .277, p = .605, partial η^2 = .014; F_2 (1, 33) = .095, p = .760, partial η^2 = .003. Therefore, it is unlikely that the onset of initial phoneme confounded the error/omission reported in Experiment 4a and Experiment 5a.

8.5 Methodology for Experiment 6b

8.5.1 Design

Experiment 6b utilised a repeated measures design. Therefore, the independent variable was word frequency (high vs. low). The dependent variables were identical to those reported in Chapter 8, Section 8.3.1.

8.5.2 Participants

Recruitment processes and selection criteria were detailed in Chapter 2, Section 2.4.2. For Experiment 6b, participants consisted of 20 (5 males and 15 females) undergraduate and postgraduate students. Participants ranged from 18 to 35 years of age and with a mean age of 20.90 (4.88) years.

8.5.3 Materials

The general materials and word frequency stimuli sets for Experiment 6b were identical to those discussed in Chapter 2, Section 2.4.3.2.

8.5.4 Procedure

The procedure was identical to that used in Experiment 6a.

8.6 Results for Experiment 6b

8.6.1 Data Preparation

Data preparation processes were discussed in Chapter 2, Section 2.5.

8.6.2 Analysis of Response Times

Table 8.2 reports the descriptive statistics for average verbal response times (ms) to low and high frequency items during picture naming. This reveals that the verbal response times for low frequency items (M_1 = 464.19, *SD* = 85.20; M_2 = 459.79, *SD* = 39.39) were similar to those for high frequency items (M_1 = 458.25, *SD* = 84.37; M_2 = 452.05, *SD* = 33.09). This data suggested that there was little variation between the verbal response times for low and high frequency items during delayed picture naming.

Table 8.2 Average response times and error/omission rates for Experiment 6b

Measure	By-Item Mean (SD)	By-Subject Mean (SD)
Low frequency response time	459.79 (39.39)	464.19 (85.20)
High frequency response time	452.05 (33.09)	458.25 (84.37)
Low frequency error/omission	2.85 (1.84)	4.85 (3.18)
High frequency error/omission	2.41 (1.59)	4.15 (3.36)

To maintain consistency with the analyses performed in previous chapters, verbal response times for low and high frequency items were analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This revealed that there were no significant main effects of word frequency on verbal response times by-subject or by-item; F_1 (1, 19) = 1.062, $p > .05$, partial $\eta^2 = .053$; F_2 (1, 33) = 1.036, $p > .05$, partial $\eta^2 = .030$. Therefore, the verbal response times elicited by low frequency items were no slower than the verbal response times elicited by high-frequency items during delayed picture naming. This suggests that the response times reported for Experiment 4b (Chapter 6) and Experiment 5b (Chapter 7) were not confounded by the onset of initial phoneme.

8.6.3 Analysis of Error/Omission Rates

Table 8.2 also presents the descriptive statistics for average error/omission rates produced for low and high frequency items during delayed picture naming. This demonstrates that error/omission rates for low frequency items (M_1 = 4.85, *SD* = 3.18; M_2 = 2.85, *SD* = 1.84) were similar to those for high frequency items (M_1 = 4.15, *SD* = 3.36; M_2 = 2.41, *SD* = 1.59). Error/omission rates were also analysed by-subject and by-item using 2 separate repeated measures analyses of variance. This revealed that there were no main effects of word frequency on error/omission rates by-subject or by-item during delayed picture naming; F_1 (1, 19) = 1.789, $p > .05$, partial $\eta^2 = .197$; F_2 (1, 33) = 1.101, $p > .05$, partial $\eta^2 = .302$. Therefore, it is unlikely that the onset of initial phoneme confounded the error/omission reported in Experiment 4b (Chapter 6) or Experiment 5b (Chapter 7).

8.7 Discussion of Results for Experiments 6a-6b

Chapter 8 presented two semi-factorial experiments which investigated the effects of AoA (Experiment 6a) and word frequency (Experiment 6b) on verbal response times and error/omission rates during delayed picture naming. This experimental paradigm was introduced to the programme of research to identify if difficulties in initiating articulation may have confounded the results reported in Chapter 6 (Immediate Picture Naming) and Chapter 7 (Immediate Word Reading). Indeed, although the stimuli sets which were used throughout this programme of research were established using measures of AoA, word frequency, word length, orthographic neighbourhood density, category typicality, picture-name agreement, visual complexity and familiarity; the stimuli sets were not matched for initial phoneme during the research design process. This suggested that initial phoneme may have confounded verbal response times (Catling & Johnston, 2009; Ghyselinck, Lewis & Brysbaert, 2004; Holmes & Ellis, 2006; Johnston & Barry, 2006; Juhasz, 2005; Morrison & Ellis, 1995, 2000; Navarrete et al. 2013). For example, if initial phoneme confounded the results which were reported in Chapter 6 and Chapter 7, the slower response times for later acquired stimuli may reflect difficulties in initiating articulation rather than valid and reliable effects of AoA (Catling & Johnston, 2009; Ghyselinck, Lewis & Brysbaert, 2004; Holmes & Ellis, 2006; Johnston & Barry, 2006; Lewis, 2006; Morrison & Ellis, 1995, 2000; Navarrete et al. 2013).

However, Experiment 6a demonstrated that there were no significant effects of AoA or word frequency on verbal response times during delayed picture naming. Furthermore, there were also no significant effects of AoA or word frequency on error/omission rates during delayed naming. These findings suggest that the stimuli sets which were used throughout this programme of research were not susceptible to the effects of initial phoneme and that the verbal response times which were reported in Chapter 6 and Chapter 7 were not confounded by difficulties in initiating articulation (Catling & Johnston, 2009; Ghyselinck, Lewis & Brysbaert, 2004; Holmes & Ellis, 2006; Morrison & Ellis, 1995, 2000; Navarrete et al. 2013). The implications for the hypotheses which were proposed for Experiments 6a and 6b are presented in Table 8.3.

Table 8.3 Implications for the hypotheses presented for Experiments 6a and 6b

Hypothesis	Evidence
If the results reported in Chapter 6 and Chapter 7 were confounded by initial phoneme, earlier acquired items will elicit significantly faster response times than those observed for later acquired items during delayed picture naming.	Not Supported
Later acquired items will elicit significantly more errors/omissions than earlier acquired items.	Not Supported
If the results reported in Chapter 6 and Chapter 7 were confounded by initial phoneme, high frequency items will elicit significantly faster response times than those observed for low frequency items during delayed picture naming.	Not Supported
Low frequency items will elicit significantly more errors/omissions than high frequency items.	Not Supported

These findings are consistent with previous studies which have also documented significant effects of AoA and word frequency in immediate naming conditions and null effects of AoA and word frequency in delayed naming conditions (Catling & Johnston, 2005; Holmes & Ellis, 2006; Johnston & Barry, 2006). Indeed, Catling and Johnston (2009), Ellis and Morrison (1998) and Holmes and Ellis (2006) also reported significant effects of AoA during immediate picture naming and null effects of AoA during delayed picture naming. However, as discussed in Chapter 8, Section 8.2, Experiment

6a and Experiment 6b also expanded on previous findings by incorporating a variable delay to improve the validity of this experimental paradigm. Indeed, Catling and Johnston (2009) and Holmes and Ellis (2006) only incorporated one delay in their research designs. This methodological limitation may have confounded previous results due to the predictability of the cued response. In contrast, Experiment 6a and Experiment 6b incorporated variable and randomised delays to remove this predictability and ensure that although participants could plan their response during the delay, they could not initiate articulation prior to the presentation of the cue. Consequently, the findings reported in this chapter suggest that the effects of AoA on verbal response which were reported in Chapter 6 and Chapter 7 of this thesis were not confounded by or reducible to the effects of initial phoneme.

However, it must be noted that although the stimuli sets were matched for a large number of psycholinguistic properties (see Chapter 2, Section 2.4.3.1 and Section 2.4.3.2) and the experimental paradigms reported in this programme of research produced consistent findings, further research is required to explore the potential loci of AoA effects. Indeed, this programme of research has reported significant and reliable effects of AoA on response times during perceptual identification, picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading but each of these experimental paradigms assessed different aspects of cognitive processing (please see Chapter 2, Table 2.1). Further research is required to identify if any of these effects were significantly larger or smaller than others because this could differentiate between strong, moderate and weak effects of AoA within the cognitive system. Therefore, Chapter 9 reports a comparison of the effect sizes exerted by AoA on response times during perceptual identification, picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading. This comparison of effect sizes was incorporated into this programme of research to facilitate the identification and exploration of potential loci of AoA effects within the cognitive system. However, the effects of word frequency were not re-examined in Chapter 9 due to the null results which were reported in the previous chapters of this thesis.

8.8 Chapter Conclusion

Chapter 8 reported two semi-factorial experiments which investigated the effects of AoA (Experiment 6a) and word frequency (Experiment 6b) on response times and error/omission rates during delayed picture naming. Experiment 6a and Experiment 6b revealed that there were no significant effects of AoA or word frequency on response times or error/omission rates during delayed picture naming. These findings suggest that the results reported in Chapter 6 (Immediate Picture Naming) and Chapter 7 (Immediate word reading) were not confounded by difficulties during the initiation of articulation. However, further examination of the AoA effect sizes which were reported in this thesis was also required for the researcher to identify the potential loci of AoA effects. Therefore, Chapter 9 reports a comparison of the AoA effects which were observed during Experiments 1a, 2a, 3a, 4a and 5a. This enabled the researcher to explore the potential locus or loci of AoA effects in relation to the findings reported in this thesis and the theoretical perspectives presented in Chapter 1.

Chapter 9: Comparison of AoA Effects

9.1 Chapter Overview

The previous experimental chapters have reported significant main effects of AoA on response times during perceptual identification (Chapter 3), picture-category verification/falsification (Chapter 4), picture-name verification/falsification (Chapter 5), immediate picture naming (Chapter 6) and immediate word reading (Chapter 7). Consequently, Chapters 3-7 demonstrated that earlier acquired items were processed significantly faster than later acquired items across all of the experimental paradigms, even when word frequency, word length, picture-name agreement, orthographic neighbourhood density, visual complexity, imageability, concreteness and familiarity were controlled. Furthermore, the null effects which were reported in Chapter 8 for delayed picture naming suggested that the effects of AoA on verbal response times during immediate picture naming and immediate word reading were not confounded by difficulties in iniitating articulation. In contrast, no consistent effects of word frequency were observed across these tasks when AoA and the other psycholinguistic properties listed above were controlled. This suggests that AoA exerted significant effects during the aspects of perceptual, semantic and lexical processing assessed by this programme of research, but word frequency did not. However, further examination of the data was required to identify which tasks elicited the greatest effects and to also explore the potential locus (or loci) of AoA effects. Therefore, Chapter 9 reports a data synthesis and comparison of the effect sizes of AoA on response times during Experiments 1a (Chapter 3), 2a (Chapter 4), 3a (Chapter 5), 4a (Chapter 6) and 5a (Chapter 7). This was performed by-subject so that Cohen's *d* values could be calculated for each individual participant and these effect sizes could then be entered into a univariate analysis of variance with experimental paradigm selected as the independent variable and Cohen's *d* selected as the dependent variable. This enabled the comparison of the AoA effects reported in this thesis. However, word frequency was not re-examined in this chapter due to the absence of significant and consistent effects throughout the experimental paradigms reported in the previous experimental chapters.

9.2 Rationale for Analysing AoA Effects

Several theories concerning the locus or loci of AoA effects have been proposed and these perspectives were discussed in detail in Chapter 1, Section 1.2.1 (the PCH), Chapter 1, Section 1.2.2 (the SH) and Chapter 1, Section 1.2.3 (the multi-loci perspective). As outlined in Chapter 1 and Chapter 2, each of these theories placed the locus/loci of AoA in different levels of processing or in the case of the multi-loci perspective between levels of processing. To reiterate, proponents of the PCH argue that AoA effects arise at the level of lexical access, retrieval and articulation (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Garlock, Walley, & Metsala, 2001; Moore, Smith-Spark, & Valentine, 2004). Therefore, this model does not predict AoA effects during perceptual or semantic processing and as such, no significant effects of AoA should be observed during tasks which do not require lexical access, retrieval or articulation. However, this thesis has demonstrated that AoA effects are evident across all of the experimental paradigms reported in this thesis. Indeed, AoA effects were observed during perceptual processing; as evidenced by the perceptual identification task and the total fixation durations which were recorded during picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading. These findings are inconsistent with the PCH and suggest that this is not a valid theory of AoA.

Secondly, proponents of the SH argue that AoA exerts its influence during a semantic level of processing (Brysbaert, Van Wijnendaele, & De Deyne, 2000; Ghyselinck, Custers, & Brysbaert, 2004; Ghyselinck, Lewis, & Brysbaert, 2004; Gilhooly & Gilhooly, 1980; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989). Therefore, according to this model AoA effects should not be observed in tasks which do not require that participants process the stimuli for meaning. In this thesis, AoA did exert a significant effect on semantic processing as evidenced by the significant effects on manual response times during picture-category verification/falsification. However, the effects of AoA were stronger for tasks which required indirect semantic-lexical encoding (e.g. picture naming and picture-name verification/falsification) and tasks which by-passed semantic processing using the direct route to lexicalisation (e.g. word reading). Furthermore, AoA effects were also evident during perceptual processing. These findings suggest that AoA effects are not restricted to semantic processing.

Indeed, proponents of the multi-loci perspective argue that AoA effects are routed in the connections between levels of processing rather than at a specific stage (Ellis, Holmes, & Wright, 2010; Ellis & Humphries, 1999; Ellis & Lambon Ralph, 2000; Holmes, Fitch & Ellis, 2006; Hirsh, Morrison, Gaset, & Carnicer, 2003; Izura et al., 2011; Lake & Cottrell, 2005; Lewis, 2006; Morrison, Hirsh, Chappell, & Ellis, 2002). They also argue that these effects should be most pronounced when the mapping between levels of representation are arbitrary (such as during picture-name verification and picture naming) and lower in tasks where the mapping between levels of processing is transparent (such as during word reading in English) (Chen, Zhou, Dunlap & Perfetti, 2007; Ellis & Lambon Ralph, 2000; Stewart & Ellis, 2008). This thesis has provided support for this theoretical perspective due to the variety of AoA effects observed across the experimental paradigms reported in the previous chapters. However, as summarised in Chapter 1, there is considerable debate concerning which of these theories (if any) best explain the nature of AoA effects (Catling & Johnston, 2009; Ghyselinck, Custers & Brysbaert, 2004; Johnston & Barry, 2006; Juhasz, 2005; Juhasz & Rayner, 2003; You, Chen & Dunlop, 2009; Zevin & Seidenberg, 2002, 2004).

The purpose of this thesis was to enable the researcher to design and implement a systematic programme of research which would evaluate these theories by identifying when AoA exerts the strongest influence (or influences) on the cognitive system. This was accomplished through the rigorous control and manipulation of the methodological elements reported in this thesis. For example, the same stimuli sets, equipment, display times, display formats and population were used throughout this thesis. This enabled the researcher to standardise the data at the time of collection rather than during the analyses, thereby increasing experimental control. This addressed a significant limitation of previous research which has often attempted to compare AoA effects across experimental tasks which have employed different stimuli sets, samples, procedural elements and analytical techniques (Brysbaert & Ghyselinck, 2006; Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Consequently, this research produced data which was comparable across all of the experimental paradigms without the requirement of statistical manipulation of data.

The previous chapters have indicated that AoA exerts significant main effects on response times during all of the experimental paradigms reported in Chapters 3-7. When findings were considered in isolation in the previous experimental chapters, it was argued that the results were most consistent with the multi-loci perspective. However, it was necessary to contextualise these findings to understand this pattern of results in more detail. Consequently, Chapter 9 reports a data synthesis of the response time data to identify the tasks in which AoA exerted the strongest influence. This analysis served the important function of identifying which of the key theories concerning the locus or loci of AoA effects has received the most support during this programme of research.

9.2.1 Hypothesis

To test the relative contributions of loci which occurred during perceptual, semantic and lexical levels of processing, this chapter reports a comparison of the effect sizes observed across the experimental paradigm reported in Chapters 3-7. Consistent with the multi-loci perspective, it was predicted that AoA would have exerted a significantly stronger effect on response times during immediate picture naming than during perceptual identification, picture-name verification/falsification, picture-category verification/falsification and immediate word reading.

9.3 Methodology

9.3.1 Design

This data synthesis employed an independent samples design in which experimental paradigm (perceptual identification x picture-category verification/falsification x picture-name verification/falsification x immediate picture naming x immediate word reading) was entered as the independent variable and effect size of AoA was entered as the dependent variable. Effect size of AoA was operationalised as the Cohen's *d* for each individual who participated in the previous experiments reported in Chapters 3-7. Cohen's *d* was calculated for response times using the formula below.

Late Acquired Mean – Early Acquired Mean / Pooled Standard Deviation

9.3.2 Participants

For the comparison of effect sizes, response time data were collected from the 108 participants (19 males, 89 females) who completed Experiments 1a, 2a, 3a, 4a and 5a. Participants ranged from 18 to 49 years of age with a mean age of 23.64 (7.13). Due to the null effects which were reported for delayed picture naming, no data from the participants who completed Experiment 6a were included in the data synthesis.

9.3.3 Materials

Materials were those detailed in the previous experimental chapters and stimuli characteristics were discussed in Chapter 2, Section 2.4.3.2. No additional materials were required for the data synthesis.

9.3.4 Data Preparation

Although partial η^2 was considered in the previous experimental chapters, there are arguments that partial η^2 over-estimates effect size and that aggregated data is less reliable than individual level data due to the latter averaging responses across participants (Dancey & Reidy, 2004; Field, 2005). In contrast, these biases are not observed when interpreting Cohen's *d* as derived from individual level data. Therefore, Cohen's *d* was calculated for each individual participant using the raw response time data which was collected for the experimental paradigms reported in this thesis. Similar and significant effects of AoA were observed for both verification and falsification during Experiment 2a (Chapter 4) and Experiment 3a (Chapter 5) and there was no interaction between AoA and the response criterion. Therefore, Cohen's *d* was calculated using the average response time across trials requiring both verification and falsification. These effect sizes of AoA on response times for perceptual identification, picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading were then entered a univariate analyses of variance with experimental paradigm entered as the independent variable and Cohen's *d* entered as dependent variable.

9.4 Comparison of AoA Effect Sizes

9.4.1 Descriptive Statistics for Response Times

Descriptive statistics for response times to earlier and later acquired items were presented in the previous experimental chapters.

9.4.2 Synthesis of AoA Effect Sizes for Response Time Data

The average Cohen's *d* values for each of the experimental paradigms are presented in Table 9.1. This table demonstrates that the strongest effect of AoA on response times was observed during immediate picture naming (*M* = 1.25, *SD* = .55), followed by immediate word reading (*M* = .68, *SD* = .44), picture-category verification/falsification (*M* = .47, *SD* = .31), picture-name verification/falsification (*M* = .43, *SD* = .26) and perceptual recognition (*M* = .39, *SD* = .57). Therefore, this reiterates that AoA exerted a significant effect on response times for every experimental paradigm reported in this thesis. This table also suggested that the effects of AoA which were observed during picture-category verification/falsification and picture-name verification/falsification were similar while the effects of AoA which were observed during immediate picture naming were considerably stronger. However, the effect of AoA reduced during immediate word reading; although the effect size of AoA during immediate word reading remained higher than those observed during perceptual identification, picture-category verification/falsification and picture-name verification/falsification. This pattern of results is consistent with the multi-loci principle that AoA effects are most prominent in tasks which involve arbitrary mapping between levels of processing. Indeed, as discussed previously, picture-naming relies on arbitrary mapping between perceptual, semantic and lexical processing.

Table 9.1 Cohen's d values for each dependent variable entered into the analysis

Experimental paradigm	Cohen's *d* (*SD*)	Effect Size Category*
Perceptual Identification	.39 (.71)	Moderate
Picture Category Verification/Falsification	.47 (.31)	Moderate
Picture Name Verification/Falsification	.43 (.26)	Moderate
Immediate Picture Naming	1.25 (.55)	High
Immediate Word Reading	.68 (.44)	High

Note. * Based on Cohen's (1988) criteria.

Individual level Cohen's *d* values were subsequently compared using a univariate analysis of variance with experimental paradigm entered as the independent variable and Cohen's d entered as the dependent variable. This revealed a significant main effect of experimental paradigm on Cohen's *d*, F (4, 103) = 12.113, $p < .001$. Multiple comparisons using Tukey HSD revealed that Cohen's *d* was significantly higher for immediate picture naming than for perceptual identification (p < 0.001) picture-category verification/falsification ($p < .001$), picture name verification/falsification ($p < .001$) and immediate word reading ($p = .001$). No other significant differences in Cohen's *d* values between experimental paradigms were observed (all $p > .1$). Therefore, the hypothesis presented in Chapter 9, Section 9.1.1 was supported. Indeed, the strongest effect of AoA was observed during immediate picture naming.

9.5 Discussion

Chapter 9 has reported a comparison of effect sizes of AoA effects across the experimental paradigms reported in this thesis. In regards to response time, this analysis has demonstrated that the strongest effect of AoA on response times was observed during immediate picture naming and that this effect was significantly higher than those observed for perceptual identification, picture-category verification/falsification, picture-name verification/falsification and immediate word reading. This supports the hypothesis which was presented in Chapter 9, Section 9.1.1 and suggests that the greatest effects of AoA were evident in a task which involved arbitrary mapping between all levels of processing (Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Juhasz, 2005; Lambon Ralph & Ehsan, 2006). As outlined in Chapter 2, Section 2.2.5, immediate picture naming was the only experimental paradigm of those entered into the analysis which relies upon the combination of arbitrary mapping between perceptual-semantic and semantic-lexical encoding (Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Juhasz, 2005; Lambon Ralph & Ehsan, 2006). Indeed, in the case of immediate picture naming, there is no correspondence between a pictured object and the corresponding label stored in the mental lexicon.

Table 9.2 states the implications for these findings for each of the theoretical perspectives discussed in Chapter 1. The pattern of results is inconsistent with the PCH prediction that AoA effects would only be observed in tasks which require direct lexical access, retrieval and articulation (Barry, Hirsh, Johnston, & Williams, 2001; Brown & Watson, 1987; Garlock, Walley, & Metsala, 2001; Moore, Smith-Spark, & Valentine, 2004). Indeed, contrary to this prediction, strong and significant AoA effects were evident across all experimental including perceptual identification and picture-category verification/falsification. However, the effects of AoA were strongest during picture naming which relies predominantly on perceptual-semantic encoding and the indirect route to lexicalisation, rather than a direct route to lexicalisation via orthographic properties. As outlined in Chapter 1, Section 1.2.1, this pattern of findings is also consistent with previous studies which have documented significant effects of AoA in tasks which do not require direct lexical access or lexical retrieval (Catling & Johnston, 2006a, 2006b, 2009; Cuetos, Aguado, Izura, & Ellis, 2002; Ellis et al., 2006; Ellis, 2012; Silveri, Cappa, Mariotti, & Puopolo, 2002). Therefore, it has been demonstrated in this thesis that the PCH does not explain the pattern of AoA effects which were observed across the experimental paradigms reported in the previous chapters. For example, the PCH does not explain the dissociation between the strong AoA effects observed during tasks which require the indirect route to lexicalisation and the weaker AoA effect observed during a task requiring the direct route to lexicalisation. These finding are counterintuitive to the predictions of the PCH.

Table 9.2 Predicted effects of AoA based on theoretical models

Theory	Summary	Predicted Effects	Outcome
Phonological Completeness	Effects restricted to tasks requiring lexical access and retrieval.	The strongest effects of AoA should be observed during word reading.	Not supported
Semantic Hypothesis	Effects restricted to tasks requiring semantic processing and most pronounced in tasks which a prominent semantic component.	The strongest effects of AoA should be observed during picture-category verification/falsification.	Not supported
Multi-Loci Perspective	Effects distributed throughout the cognitive system and most pronounced when the mapping between levels of processing is arbitrary.	AoA effects should be observed during all tasks. The effects should be most pronounced during picture naming.	Supported

The pattern of results reported in this thesis may also be inconsistent with the SH, which predicts that the strongest effects of AoA will emerge during tasks which have a prominent semantic focus (Brysbaert, Van Wijnendaele, & De Deyne, 2000; Ghyselinck, Custers, & Brysbaert, 2004; Ghyselinck, Lewis, & Brysbaert, 2004; Gilhooly & Gilhooly, 1980; Steyvers & Tenenbaum, 2005; van Loon-Vervoorn, 1985, 1989). For example, in regards to the experimental paradigms which were used in this thesis, the strongest effects of AoA on response times should have occurred during picture-category verification/falsification. However, as highlighted by the data synthesis, lower effects were observed during picture-category verification/falsification than during immediate picture naming and immediate word reading. This is counterintuitive to a purely semantic locus of AoA effects. As outlined in Chapter 2, Section 2.2.4, although immediate picture naming tasks can involve access to semantic information, the most effortful processing during this task occurs during semantic-lexical encoding (Catling & Johnston, 2009; Johnston & Barry, 2006; Juhasz, 2005; Lambon Ralph & Ehsan, 2006). Furthermore, the moderate effect of AoA during perceptual identification also suggests that may be a locus – or loci – of AoA during initial recognition processes.

The pattern of results reported in this thesis supports the multi-loci perspective (Ellis, Holmes, & Wright, 2010; Ellis & Lambon-Ralph, 2002; Holmes, Fitch & Ellis, 2006; Lewis, 2006; Stewart & Ellis, 2008). For example, as predicted by this theory, the effects of AoA were evident in all of the experimental paradigms reported in this thesis. This suggests that AoA influences perceptual processing, semantic processing, direct lexical access, indirect lexical access, lexical retrieval and articulation. The strongest effects of AoA were detected during immediate picture naming, which relies on arbitrary mapping between all levels of representation (Catling & Johnston, 2009; Catling, Dent, Preece & Johnston, 2013; Johnston & Barry, 2006; Juhasz, 2005; Lambon Ralph & Ehsan, 2006). This supports the multi-loci principle that AoA exerts its strongest effect when the mapping between levels of processing is arbitrary (Catling & Johnston, 2006a, 2006b, 2006c; Dent, Catling, & Johnston, 2007; Izura & Ellis, 2002, 2004; Johnston & Barry, 2006; Lake & Cottrell, 2005; Stewart & Ellis, 2008). Indeed, there was a clear distinction between the strong effects of AoA during indirect lexical access and the weaker effects of AoA during direct lexical access. This suggests that these AoA effects arose between semantic and lexical processing rather than at a specific stage of processing as localist perspectives would predict (Catling & Johnston, 2009; Ellis & Lambon Ralph, 2000).

These findings support previous research conducted by Catling and Johnston (2009), who argued that there are at least two distinct and prominent loci of AoA effects with the first locus occurring between early structural/perceptual and semantic processing and the second occurring between semantic and lexical processing. In the case of this thesis, tasks such as picture-category verification/falsification and picture-name verification/falsification rely most extensively on structural/perceptual processing and semantic processing while tasks such as picture naming rely more extensively on semantic and lexical processing (Barry, Johnston & Wood, 2006; Johnston & Barry, 2006; Juhasz, 2005; Juhasz & Rayner, 2003, 2006; Lambon Ralph & Ehsan, 2006). This could explain why the effects of AoA were significantly lower during picture-category verification/falsification than during immediate picture naming. Indeed, it implies AoA effects are more prominent in the mapping between semantic and lexical processing than in the mapping between perceptual and semantic processing. Furthermore, the findings reported in this chapter also expand Catling and Johnston's (2009) findings by suggesting that direct and indirect lexical access are differentially affected by AoA. Indeed, as outlined in Chapter 2, Section 2.2.5 the transparent mapping between orthography and phonology which arises during word reading also means that this task relies on structural processing (Ellis & Morrison, 2000; Johnston & Barry, 2006). This transparent correspondence between orthography and phonology enables participants to access information in the lexicon directly by by-passing semantic processing. In contrast, immediate picture naming relies on the indirect route to lexical access and retrieval which is theorised to occur between semantic and lexical processing. This could explain why the AoA effect which was observed during immediate picture naming was significantly higher than that observed during word reading if the indirect route to lexical access is more susceptible to AoA than the direct route to lexical access due differences in the transparency between levels of processing. Indeed, Lambon Ralph and Ehsan (2006) identified a large AoA effects during picture naming which was not replicated during word reading when word frequency, visual complexity, name agreement and word length were controlled. This adds further support to the proposition that the direct and indirect routes to lexical access are differentially affected by AoA.

9.6 Chapter Conclusion

Chapter 9 has reported a data synthesis of the response time data from Experiments 1a (Chapter 3), 2a (Chapter 4), 3a (Chapter 5), 4a (Chapter 6) and 5a (Chapter 7). It has been demonstrated that the strongest effects of AoA were observed during immediate picture naming. These findings were interpreted with reference to the PCH, the SH and the multi-loci perspective. It was argued that the patterns of results which have been reported in this thesis are most consistent with the multi-loci perspective of AoA which was presented by Ellis and Lambon Ralph (2000). Indeed, although significant AoA effects were observed across all of the experimental paradigms, they were strongest in a task which most relied on arbitrary mappings between all levels of processing. Chapter 10 subsequently presents a general discussion of the programme of research. In this chapter, the research identifies how this programme of research has presented original contributions to knowledge and addressed each of the objectives outlined in Chapter 1. The researcher also discusses the limitations of this programme of research and directions for future research before reflecting on the process of completing this thesis.

Chapter 10: General Discussion

10.1 Chapter Overview

The results from each the studies reported in this thesis and the implications these findings posed for the key theoretical perspectives (see Chapter 1) have been discussed in the previous experimental chapters. The findings from this programme of research were also contextualised by the comparison of effect sizes reported in Chapter 9. Indeed, this revealed substantial support for the multi-loci perspective due to the identification of two distinct loci of AoA effects occurring between perceptual-semantic processing and semantic-lexical processing respectively. Chapter 10 subsequently presents a general discussion of this programme of research. The purposes of this chapter are to summarise the main findings, identify how each of the original objectives (Chapter 1, Section 1.3.1) have been met, evaluate the programme of research, explore avenues for further research and reflect on the process of completing this thesis.

It is argued in this chapter, that the systematic programme of research has provided several original contributions to knowledge. Firstly, it has presented, tested and evaluated new, standardised, highly reliable and valid semi-factorial stimuli sets for both AoA and word frequency. This addressed the limitation of previous research which occasionally employed poorly standardised stimulus sets (Alvarez & Cuetos, 2007; Brysbaert & Cortese, 2011; Brysbaert & New, 2009; Cortese & Khanna, 2007; Lewis, 2006; Zevin & Seidenberg, 2002). Secondly, the methodological adaptations which were employed during this research enabled the researcher to expand on the available methodologies for use in AoA and word frequency research. Indeed, it has been demonstrated in this thesis that eye-tracking can be combined with a variety of the contemporary experimental paradigms to obtain time sensitive indicators of perceptual processing speed in addition to the indirect measures of cognitive processing obtained using conventional experimental techniques. Furthermore, this systematic, multi-task investigation maintained rigorous experimental control across the various experimental paradigms reported in this thesis. This facilitated the comparison of effect sizes across different experimental paradigms where methodological inconsistencies would have previously compromised these analyses (see Chapter 1, Section 1.2). This methodological adaptation can be reemployed in future research to assess the generalisability of the findings reported in this thesis. Indeed, it would be useful to examine if the effects of AoA on response times and total fixation durations reported in this thesis can be replicated when investigating AoA effects in other languages, when using alternative materials and when employing different experimental paradigms than those reported in this thesis. Finally, this programme of research has provided valuable insights into the nature and loci of AoA effects within the cognitive system. Although significant AoA effects were observed across all of the experimental paradigms, the effects were strongest in tasks which required indirect lexical access and retrieval. As argued in the previous chapters, this pattern of results is consistent with the multi-loci perspective of AoA effects but it is inconsistent with the predictions of the SH and the PCH. For example, when interpreted in context, the consistent pattern of significant AoA effects across all of the experimental paradigms, the dissociation between AoA and word frequency and the differential effect of AoA on direct and indirect lexical processing lends substantial support to the predictions of the multi-loci perspective discussed in Chapter 1, Section 1.2.3.

10.2 Summary of Main Findings

The following points summarise of the main findings which were discussed in Chapters 3-9.

- AoA exerted significant and consistent effects on VDTs, manual response times, verbal response times and total fixation durations (see Table 10.1). This suggests that AoA effects are pervasive throughout the cognitive system.
- The only significant, consistent effects of AoA on error/omission rates were observed during perceptual identification. Interpreted in the context of the first point, this suggests that AoA exerted a more pronounced effect on response times than response accuracy. However later acquired items may be more susceptible to error than earlier acquired items during initial recognition.
- AoA effects were detected across all of the experimental paradigms reported in this thesis, despite the rigorous control of other psycholinguistic properties (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Contrary to the assertions of Zevin and Seidenberg (2002, 2004), this suggests that AoA is a valid and reliable measure which exerts a significant and independent influence on processing.
- Word frequency did not exert a consistent, significant effect on VDTs, manual response times, verbal response times, total fixations or error/omission rates when AoA and the other psycholinguistic properties were controlled. This demonstrates that the AoA effects were not reducible to the effects of word frequency. It also suggests that further research may be required to identify if previous word frequency stimuli sets were confounded by other properties.

- The results reported for delayed picture naming (Chapter 8) demonstrated that the verbal response times reported for immediate picture naming (Chapter 6) and immediate word reading (Chapter 7) were not confounded by difficulties in initiating articulation.
- The strongest effect of AoA was observed during tasks which required indirect lexical access (e.g. picture naming and picture-name verification/falsification). Weaker, but moderate, effects of AoA were observed during tasks which relied on direct lexical access (e.g. word reading), semantic processing (e.g. picture-category verification/falsification) and perceptual processing (e.g. perceptual identification). As outlined in Chapter 9, this is most consistent with the multi-loci perspective. Indeed, as direct lexical access and indirect lexical access were differentially affected by AoA, this supports the argument that AoA effects arise in the connections between levels of processing and that they are most evident when the mapping between levels of processing is arbitrary.
- The pattern of results lends considerable support to the proposition that there are at least two loci of AoA effects which appear prior to articulation (Catling & Johnston, 2009). For example, a strong locus can be observed between semantic and lexical processing due to the differentiation between the effects of AoA observed during tasks requiring direct verses indirect lexical access and retrieval. However, a second but weaker locus can be observed between perceptual and semantic processing due to the significant effects of AoA during perceptual identification and picture-category verification/falsification.

Table 10.1 Summary of the main effects of AoA and word frequency

	Experiment A				Experiment B			
	AoA		Response Criterion		Word Frequency		Response Criterion	
Experimental paradigm	By-Subject	By-Item	By-Subject	By-Item	By-Subject	By-Item	By-Subject	By-Item
Perceptual Identification								
Decision Times	✓	✓			X	X		
Error/Omission Rates	✓	✓			X	X		
Visual Duration Thresholds	✓	✓			X	X		
Picture-Category Verification/Falsification								
Response Times	✓	✓	✓	✓	X	X	✓*	✓
Error/Omission Rates	X	X	X	✓	X	X	✓	X
Fixation Durations	✓	✓	✓	✓	X	X	X	X
Picture-Name Verification/Falsification								
Response Times	✓	✓	✓	✓	X	X	✓	✓
Error/Omission Rates	X	✓	X	X	✓	X	✓*	X
Fixation Durations	✓	✓	X	X	X	X	X	X
Immediate Picture Naming								
Response Times	✓	✓			X	X		
Error/Omission Rates	X	✓			X	X		
Fixation Durations	✓	✓			X	X		
Immediate Word Reading								
Response Times	✓	✓			X	X		
Error Rates	X	X			X	X		
Fixation Durations	✓	✓			X	X		
Delayed Picture Naming								
Response Times	X	X			X	X		
Error/Omission Rates	X	X			X	X		

Note. *Interaction between the response criteria and word frequency

10.3 Revisiting the Objectives of this Thesis

The following sections discuss how each of the objectives presented in Chapter 1, Section 1.3.1 have been met through the process of completing this programme of research. These objectives were developed to enable the researcher to investigate the nature and loci of AoA and word frequency effects using a systematic, comprehensive and purposeful methodological approach.

10.3.1 Resolve Limitations of Previous Research

As outlined in Chapter 1, there has been a tendency for researchers to design and implement single task studies or multi-task investigations which contained procedural inconsistencies across the different experimental paradigms (Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Lewis, 2006; Zevin & Seidenberg, 2002, 2004). This does not enable valid and reliable comparison of AoA effects across these studies (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). For example, it is not feasible to compare the effects of AoA across tasks if display times, stimuli sets and sample characteristics were not matched across these tasks. All of these factors can exaggerate or mask significant differences in effect size across experimental paradigms (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). In contrast, the research design employed during the current programme of research enabled the researcher to control methodological elements across experimental paradigms. Indeed, all of the experiments reported in this thesis employed the same AoA or word frequency stimuli sets, sampled from the same student population, displayed stimuli for the same maximum durations, recorded similar measures, presented stimuli of identical sizes and resolutions and were characterised by the same analytical procedures. This enables comparison of AoA effects across the individual studies reported in this thesis.

As outlined in Chapter 1, Section 1.2.3, the use of single studies can also hinder the ability of researchers to test the multi-loci perspective of AoA effects. Indeed, due to being derived from connectionist principles, this theory requires the use of tasks which involve multiple levels of processing, incorporate arbitrary mapping between levels of processing and high degrees of experimental control over the stimuli, procedure and data collection (Ellis, Holmes, & Wright, 2010; Ellis & Humphries, 1999; Ellis & Lambon Ralph, 2000; Izura & Ellis, 2002, 2004; Lake & Cottrell, 2005; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008). The researcher addressed this issue through the design and implementation of a systematic multi-task investigation in which each experimental paradigm assessed different aspects of cognitive processing. This facilitated the assessment of the multi-loci perspective by enabling the researcher to explore potential loci of AoA effects at and between levels of processing. Consequently, it was possible to differentiate between significant AoA effects which arose firstly between perceptual processing and semantic processing and secondly between semantic processing and lexical processing (Catling & Johnston, 2009; Ellis, Holmes, & Wright, 2010; Stewart & Ellis, 2008).

Previous studies that investigated the effects of AoA have traditionally employed non-factorial designs which are more susceptible to the confounding effects of extraneous variables and also possess lower experimental control and poorer statistical power than fully-factorial and semi-factorial designs (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). These studies have also been accused of incorporating stimuli sets which are established using normative data which is arguably unreliable (Brysbaert & Cortese, 2011; Brysbaert & Ghyselinck, 2006; Brysbaert & New, 2009; Johnston & Barry, 2006; Juhasz & Rayner, 2003, 2006; Morrison, Chappell & Ellis, 1997). Therefore, another way in which the researcher resolved the limitations of previous research was through the use of a semi-factorial design and stimuli sets which were tightly controlled for a wide variety of psycholinguistic variables (see Chapter 2, Section 2.4.3).

10.3.2 Extending Experimental Paradigms Used in AoA Research

One of the ways in which the researcher extended the experimental paradigms reported in this thesis was through the design of large, valid, reliable and semi-factorial stimuli sets for AoA and word frequency. This was a complex, time consuming and vital adaptation which was accomplished through a painstaking process of matching the stimuli sets for each of the other psycholinguistic properties controlled during this programme of research (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Indeed, after the initial median split on the AoA and word frequency measures respectively, items were manually rearranged in the stimuli sets based on their additional psycholinguistic properties to ensure all of these potentially confounding variables were controlled during experimental design. The stimuli sets were used for all of the experimental paradigms reported in this thesis. This enhanced the power, validity and reliability of the research through the use of a controlled, systematic and semi-factorial design (Brysbaert & Ghyselinck, 2006; Lewis, 2006). The decision was made to establish tightly controlled semi-factorial stimuli sets due to this optimising generalisability and experimental control. Indeed, a fully factorial stimuli set would have consisted of significantly fewer items due to the highly intercorrelated nature of the psycholinguistic properties and particularly the relationship between AoA and word frequency (Barry, Johnston, & Wood, 2006; Lambon Ralph & Ehsan, 2007; Law, Wong, Yeung, & Weekes, 2008; Law & Yeung, 2010; Raman, 2006; Shibahara, Zorzi, Hill, Wydell, & Butterworth, 2003). This would have reduced the generalisability of the findings and the power of the analyses. In contrast, non-factorial stimuli sets are highly susceptible to the influence of extraneous variables, which are not controlled during experimental design and must then be incorporated in to the correlational analyses. This type of stimuli set and analysis would have evoked significantly lower experimental control than the semi-factorial stimuli sets and analysis of variance (Lewis, 2006; Zevin & Seidenberg, 2002, 2004).

Another way in which the researcher expanded the bank of available methodologies was through obtaining time-sensitive measures of perceptual processing through the measurement of VDTs during a perceptual identification task and total fixation durations during the picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading tasks. Indeed, only three previous studies have investigated the effects of AoA on VDTs during perceptual identification when word frequency was controlled (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006c; Dent, Catling & Johnston, 2007). However, none of these studies investigated the effects of word frequency. Consequently, Experiment 1b was the first to investigate if word frequency exerted a significant effect on VDTs during perceptual identification when AoA was controlled (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006c; Dent, Catling &

Johnston, 2007). Furthermore, none of the previous studies investigated if AoA and word frequency exerted significant effects on decision times during this experimental paradigm. Therefore, Chapter 3 expanded the methodological principles of previous studies and documented significant effects of AoA on VDTs, decision times and error/omission rates while there were no significant effects of word frequency. This methodological approach enabled the identification of significant and independent effects of AoA during initial recognition processes (Catling, Dent, Preece & Johnston, 2013; Catling & Johnston, 2006c; Dent, Catling & Johnston, 2007).

It is notable that while eye-tracking has been routinely employed in other areas of psycholinguistics, the study conducted by Juhasz and Rayner (2006) was the only previous experiment to investigate the effects of AoA and word frequency on gaze fixations. For example, Juhasz and Rayner's (2006) study identified significant effects of AoA on eye-movements during the reading of target words which were embedded into sentences. In contrast, the programme of research reported in this thesis expanded these principles and investigated the effects of AoA and word frequency on total fixation durations during picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading in isolation. This enabled the researcher to identify significant effects of AoA on processing at a perceptual level across all of these experimental paradigms. This lent further support to the multi-loci perspective of AoA which predicts significant effects of AoA throughout the cognitive system, not solely during semantic or lexical processing (Ellis, Holmes, & Wright, 2010; Ellis & Lambon Ralph, 2000; Izura & Ellis, 2002, 2004; Lake & Cottrell, 2005; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008).

10.3.3 Identify the Potential Loci of AoA and Word Frequency Effects

As discussed in Chapter 1 and Chapter 2, the primary reason for employing a systematic and rigorously controlled multi-task investigation was to facilitate the comprehensive and purposeful comparison of AoA and word frequency effects across several experimental tasks which each assess different aspects of cognitive processing. Indeed, as discussed in Chapter 1, attempts to identify potential loci of AoA and word frequency effects through the comparison of results across different studies may have been confounded by methodological differences between existing studies. For example, results may not be generalisable and comparable across studies which utilise different stimuli sets, procedural elements or approaches to statistical analysis (Catling & Johnston, 2009; Lewis, 2006; Zevin & Seidenberg, 2002, 2004). Consequently, this programme of research was purposefully designed to standardise data at the time of collection by ensuring that the key methodological and analytical elements were consistent across all of the experimental paradigms reported in this thesis.

This rigorous approach revealed two consistent findings across all of the experimental paradigms reported in this thesis. Firstly, AoA exerted robust effects on response times during perceptual identification, picture-category verification/falsification, picture-name verification/falsification, immediate picture naming and immediate word reading when word frequency, word length, imageability, concreteness, familiarity, name agreement and orthographic neighbourhood density were controlled. As outlined in Chapter 9, this pattern of results suggests that there are at least two loci of AoA effects (Catling & Johnston, 2009; Ellis & Lambon Ralph, 2000). From these results, the researcher identified that is at least one early locus of AoA effects between perceptual/structural processing and semantic processing. This can be evidenced by the significant effect of AoA during picture-category verification/falsification and picture-name verification/falsification. Both of these tasks rely extensively on perceptual processing and semantic processing but do not require lexical retrieval (Bonin, Chalard, Méot, & Fayol, 2002; Chalard & Bonin, 2006; Holmes, Fitch & Ellis, 2006; Morrison, Hirsh, Chappell, & Ellis, 2002; Stadthagen-González, Damian, Pérez, Bowers, & Martin, 2009). That the effect sizes of AoA across these tasks were similar also adds additional support to the proposition that there is a locus of AoA between these levels of processing. This programme of research has also identified that there is a second locus of AoA effects between semantic and lexical processing which is significantly stronger than the earlier locus. For example, the strongest effects of AoA were observed during immediate picture naming which relies extensively on the indirect route to lexicalisation via the semantic information provided by the visually presented information (Barry, Morrison, & Ellis, 1997; Bonin, Chalard, Méot, & Fayol, 2002; Chalard & Bonin, 2006; Holmes, Fitch & Ellis, 2006; Morrison, Hirsh, Chappell, & Ellis, 2002; Nazir, Decoppet, & Aghababian, 2003). This AoA effect was also considerably higher than that observed during word reading which, in English, relies on the direct route to lexical access and by-passes semantic processing (Brysbaert, Van Wijnendaele, & De Deyne, 2000; Ghyselinck, Custers, & Brysbaert, 2004; Ghyselinck, Lewis, & Brysbaert, 2004; Steyvers & Tenenbaum, 2005). Indeed, word reading in English relies on spelling-to-sound consistency. In contrast, this is not applicable to the processing of pictorial stimuli, which are characterised by arbitrary mapping between the picture and the corresponding label stored in the mental lexicon. These results are highly consistent with the multi-loci perspective of AoA effects. Table 10.2 presents the predictions of this model against the observed results. This table demonstrates that the consistent effects of AoA across all experimental paradigms, the dissociation between AoA and word frequency effects and evidence for at least two loci of AoA effects which arose between different levels of processing adds substantial support to this theory.

The second consistent finding reported in this thesis was that there were no robust effects of word frequency on response times or response accuracy during perceptual identification, picture-category verification/falsification, picture-name verification/falsification, immediate picture naming, immediate word reading or delayed picture naming when AoA, word length, familiarity, concreteness, imageability, orthographic neighbourhood density and name agreement were controlled. Contrary to the aims and objectives of this thesis, the null effects of word frequency across the experimental paradigms reported in this thesis prevented the identification of potential loci of word frequency effects. However, although the null effects of word frequency were inconsistent with the hypotheses presented in this thesis, previous studies have often drawn inconclusive and contradictory conclusions regarding the effects of word frequency when AoA is controlled (Bonin, Fayol & Chalard, 2001; Brysbaert & Cortese, 2011; Brysbaert & Ghyselinck, 2006; Brysbaert & New, 2009; Johnston & Barry, 2006; Juhasz, 2005; Smith, Turner, Brown & Henry, 2006; Zevin & Seidenberg, 2002, 2004).

For example, in regards to immediate picture naming, Barry, Hirsh, Johnston and Ellis (2001), Bonin, Fayol and Chalard (2001) and Bonin, Chalard, Méot and Fayol (2002) all reported significant main effects of AoA but no effects of word frequency. In contrast to these findings, Ellis and Morrison (1998) and Lambon Ralph and Ehsan (2006) reported significant effects of both AoA and word frequency during picture naming. This pattern of results has also been reported by studies which utilised other experimental paradigms (Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2005, 2009; Johnston & Barry, 2006; Juhasz, 2005). Morrison and Ellis (1995) and Morrison, Hirsh and Duggan (2003) reported significant effects of AoA but no significant effects of word frequency during word reading. In contrast, Brysbaert, Lange and Van Wijnendaele (2000), Ghyselinch, Lewis and Brysbaert (2004) and Juhasz and Rayner (2006) reported significant effects of both AoA and word frequency during word reading. These findings lend support to Cuetos, Alverez, González-Nosti, Méot and Bonin's (2006) argument that the interaction between AoA and word frequency is not always reliable. Therefore, while the pattern of results reported in this thesis was surprising, it was consistent with earlier studies which have detected significant effects of AoA in the absence of word frequency effects.

The null effects of word frequency which were reported in this thesis might be explained by methodological and analytical differences between this programme of research and studies which have reported significant effects of word frequency. Indeed, Johnston and Barry (2006) identified that studies which have employed correlational designs typically detect co-occurring AoA and word frequency effects due to this approach enabling other psycholinguistic properties of stimuli to co-vary and confound results. Consequently, a larger proportion of the variance can be explained by extraneous variables (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). In contrast, studies which have employed factorial or semi-factorial designs often detect significant effects of AoA and null effects of word frequency due to the rigorous experimental control exercised during the design of these studies (Brysbaert & Ghyselinck, 2006; Catling & Johnston, 2009; Ellis & Lambon Ralph, 2000; Juhasz, 2005; Lewis, 2006;

Zevin & Seidenberg, 2002, 2004). The programme of research reported in this thesis utilised a semi-factorial design and the high degree of experimental to prevent the confounding influence of intercorrelations between AoA, word frequency, imageability, familiarity, concreteness, picture-name agreement, orthographic neighbourhood density, word length and visual complexity. While factorial designs reduce the ecological validity of findings, this approach was necessary to facilitate the comparison of effect sizes and exploration of potential loci reported in Chapter 9. However, further research is required to identify if the findings reported within this thesis are replicable under more realistic conditions.

Arguments have also been presented in the literature which suggest that the effects of word frequency are most evident and consistent when high and low frequency stimuli sets are selected from the highest and lowest extremes of the normative scale respectively; thereby emphasising the distinction between low and high frequency items by increasing the range between these stimuli sets (Barry, Hirsh, Johnston & Ellis, 2001; Brysbaert & New, 2009; Lewis, Gerhand, & Ellis, 2001; Zevin & Seidenberg, 2002, 2004). For example, Zevin and Seidenberg (2002) argued that the use of suboptimal high and low frequency items enables other psycholinguistic properties to confound results. However, although the same argument may apply to the selection of early and late acquired items, the stimuli sets which were used during this programme of research were purposefully not selected from the extremes of the normative scales for either the AoA or word frequency. Indeed, this decision was informed by counterarguments which state that selecting items from the extremes of the normative scales increases unexplained variance in non-factorial designs and significantly reduces the number of items which can be selected after meeting all of the inclusion criteria for semi-factorial designs (Brysbaert & Cortese, 2011; Brysbaert & New, 2009; Juhasz, 2005; Johnston & Barry, 2006; Lewis, 2006). Consequently, it can be argued that selecting items from the extremes of the normative scales reduces the validity, reliability and generalisability of findings (Brysbaert & New, 2009; Johnston & Barry, 2006; Lewis, 2006). This approach was therefore counterintuitive to the aims and objectives of this programme of research.

Contrary to the argument presented by Zevin and Seidenberg (2002, 2004), the null effects of word frequency were consistent across all of the experimental paradigms reported in this thesis despite items not being selected from the extremes of the normative scales for word frequency. This suggests that the effects were reliable and while a different pattern of results may be detected using high and low frequency stimuli which selected from the extremes of the normative scales for word frequency, previous studies have repeatedly demonstrated that the effects of AoA continue to supersede those of word frequency even when more stringent inclusion and exclusion criteria are used (Barry, Hirsh, Johnston & Ellis, 2001; Brysbaert & Cortese, 2011; Brysbaert & New, 2009; Catling & Johnston, 2009; Cortese et al., 2007; Ellis & Lambon Ralph, 2000; Johnston & Barry, 2006; Juhasz, 2005; Lewis, Gerhand & Ellis, 2001; Pérez, 2006). Consequently, the pattern of results reported in this thesis suggest that the effects of AoA are robust, pervasive throughout the cognitive system and independent of word frequency.

Table 10.2 Applying the findings from this thesis to theoretical models

	Theoretical Perspective			
Prediction	PCH	SH	Multi-Loci	Findings
1	AoA will exert a significant effect on the experimental paradigms which require direct lexical access and articulation (e.g. word reading).	AoA will exert a significant effect on tasks which require semantic processing (e.g. picture-category verification, picture naming verification and picture naming)	AoA will exert a significant influence on performance during all of the experimental paradigms due to processing stimuli which was acquired through interleaved learning	Significant effects of AoA were observed across all of the experimental paradigms. This supports the multi-loci perspective of AoA effects. Indeed, significant effects of AoA were observed across perceptual, semantic and lexical levels of processing.
2	AoA and word frequency effects will co-occur because the frequency of occurrence will also determine the entrenchment of the items in the mental lexicon.	AoA and word frequency effects will co-occur because the frequency of occurrence will determine the entrenchment of items in the semantic system.	AoA and word frequency effects can co-occur. However, AoA effects will be most prominent if word frequency does not exert a significant effect.	AoA exerted moderate to high effects on response times for all experimental paradigms when word frequency was controlled. In contrast, word frequency did not exert a consistent effect when AoA and other variables were controlled.
3	AoA may also influence tasks requiring indirect lexical access if there is a loci during articulation (e.g. picture naming). However, this effect will be smaller in magnitude than that observed during experimental paradigms which require direct lexical access (e.g. word reading).	AoA effects will be strongest during experimental paradigms which require extensive semantic processing (e.g. picture-category verification/falsification).	AoA effects will be largest during experimental paradigms which require the use of arbitrary mapping between levels of processing (e.g. picture naming).	The strongest AoA effects were observed during picture naming. This task relies upon arbitrary mapping between all levels of processing. These effects were significantly higher than those observed during word reading which relied upon transparent mapping.

10.4 Limitations and Future Directions

This research was the first systematic, semi-factorial, multi-task approach to investigate the nature and loci of AoA and word frequency effects using a combination of modified contemporary experimental paradigms and eye-tracking. As such, it was an exploratory process which could not exhaust the avenues for further research. Indeed, further research is required to ascertain whether the effects observed during this programme of research can be replicated using other semi-factorial stimuli sets and samples. This would enable researchers to determine if the effects observed during this programme of research are generalisable or if they are the result of sampling errors. However, this would be most accurately assessed using multi-task investigations and experimental paradigms which are characterised by the same degree of experimental control as that exercised during this programme of research.

It is important to identify if the pattern of results reported in this thesis is replicable using alternative experimental paradigms. Indeed, further exploration using different experimental paradigms which rely upon alternative aspects of cognitive processing to those examined during this thesis could identify additional loci of AoA effects. Alternatively, further research could identify that the effects reported in this thesis were task specific and not evident when using different tasks (Zevin & Seidenberg, 2002, 2004). For example, it would be useful to ascertain whether there are significant AoA exerts on perceptual processing speed during standard categorisation and visual search tasks. This could provide additional insights into the loci of AoA effects between perceptual and semantic processing. Indeed, several researchers have identified that eye-movements can reflect rapid processing of stimuli at perceptual and semantic levels (Juhasz & Rayner, 2003, 2006; Rayner, Chace, Slattery & Ashby, 2006; Rayner & Juhasz, 2004). Applying the principles developed during this thesis to experimental paradigms such as word association and lexical decision tasks could also provide additional insights into the loci of AoA effects between semantic and lexical processing (De Deyne & Storms, 2007; Catling & Johnston, 2006c; Johnston & Barry, 2005).

It is also notable that the AoA and word frequency effects reported in this thesis were derived from stimuli sets based on normative data for the United Kingdom (Morrison, Chappell & Ellis, 1997). Languages vary considerably in their transparency and the multi-loci perspective of AoA predicts that AoA effects may not be observed in languages with different orthographic characteristics (Alverez & Cuetos, 2007; Burani, Arduino, & Barca, 2007; Chen, Dent, You & Wu, 2009). Therefore, it would be useful to investigate the effects of AoA on response times, response accuracy and total fixation durations in other languages. This would enable researchers to test this multi-loci principle while using contemporary experimental paradigms in conjunction with time-sensitive measures (Juhasz & Rayner, 2003, 2006).

Another area for further investigation would be to ascertain whether AoA effects on total fixation durations remain prominent in cases of cognitive decline. Indeed, this research has investigated the nature and loci of AoA effects in a neurologically healthy student sample. While several studies have identified that earlier acquired items retain their processing advantage in clinical samples with cognitive decline, it would be useful to identify whether this residual AoA effect is due to a particular locus or several different levels of processing (Cuetos, Herrera & Ellis, 2010; Holmes, Fitch & Ellis, 2006; Rodrígues-Ferreiro et al., 2009).

10.5 Personal Reflections of the Research

As a part-time and self-funded PhD, this thesis has been completed over the course of six years and as such a considerable number of challenges and changes have been experienced during this time. This section presents a variety of personal reflections concerning the process of completing this programme of research.

10.5.1 Years One and Two

The first and second years of the programme of research featured a number of important milestones including completing postgraduate research training modules. These modules allowed me to consolidate my understanding of research processes, share information with other postgraduate students and firmly establish my theoretical understanding of both quantitative and qualitative approaches to research. It also enabled me to develop a much firmer understanding of the challenges I would experience as a doctorial candidate. For example, one of the most prominent challenges that these modules highlighted, and which I experienced throughout the process of completing this thesis, was maintaining my focus on the programme of research while studying part-time, working in various capacities and managing other commitments. This was particularly difficult while working and studying in the same department due to conflicting priorities and difficulties compartmentalising these commitments. This obstacle was resolved using strict time-management, agreeing on protected time for study with my employers and managing my own expectations for what I could achieve within the allocated time for study.

Another important milestone of this stage was the completion of an extensive literature review into the effects of AoA and word frequency, which could subsequently be updated throughout the project. Through the process of reading extensively around the topics of AoA and word frequency and by applying my existing understanding of research methodologies, I was able to identify the prominent gaps in the literature concerning the loci of AoA effects and determine which methodological paradigms would allow me to address these issues. Subsequently, I designed this systematic, semi-factorial, multi-task programme of research. These milestones also served the important function of enabling me to complete the registration process which required candidates to demonstrate extensive understanding of the topic, a comprehensive and critically considered approach and a firm understanding of the processes they would need to follow.

In terms of professional development, this stage of the PhD also coincided with the start of my experience as a research assistant in Psychology, which lasted over four years. This enabled me to gain extensive experience of conducting both quantitative and qualitative research across a wide variety of areas including cognitive, developmental, health, educational and occupational psychology. This experience substantially contributed towards my ability to design, implement, report and evaluate this programme of research and develop my skills as an independent researcher. Indeed, it provided transferable experience and an opportunity to consolidate my skills in both quantitative and qualitative research design, participant recruitment, data collection, data analysis and report writing.

10.5.2 Years Three and Four

One of the biggest challenges I experienced during this stage of the research process was that I needed to recommence my research after suspending my studies for a year after family bereavement. This was accomplished by familiarising myself with the existing and new literature and ensuring that I followed a strict routine to protect designated study time through negotiation with my supervisor and employer. An important milestone which occurred during this stage was the design, implementation, evaluation and adjustment of the experiments which were reported in this thesis. During this process I learnt how to design experiments using E-Prime and how to conduct research which incorporates both traditional experimental paradigms and eye-tracking. This was accomplished by arranging training with the technician in the Psychological Sciences department at the University of Worcester. This allowed me to substantially expand my understanding of the practical aspects and challenges of conducting a large, longitudinal, experimental and exploratory project. Indeed, it took several months to design, test, adjust and retest the semi-factorial stimuli sets which were used throughout this research. It also took several months to develop my extensive expertise in using the eye-tracking equipment. This learning process enabled me to recruit my samples and collect data for Experiments 2a, 2b, 3a and 3b during this stage of the research process.

Another important milestone of this stage was that I needed to learn how to calculate, extract, enter and analyse the data in a consistent manner across the studies reported in this thesis. For example, in order to obtain total fixation durations from the eye-tracking data it is vital to follow a comprehensive process for consolidating the raw data produced by the eye-tracker in the Eyenal software. Firstly, areas of interest (AOI) were defined based on the coordinates for the stimuli on the display. This excluded the raw data which corresponding to other regions of the visual field and ensured all data reflected fixations upon the stimuli. Secondly, using these AOI's and raw eye-movement data I needed to create fixation files and fixation sequence files using consistent criteria. This consolidated the data and produced values for total fixation durations. In contrast, response times and error/omission rates were extracted from the E-Prime software. All of these values were exported into Excel where average response times, error/omission rates and total fixation durations could be calculated by-item and by-subject and these values were then exported into SPSS for analyses. The analysis process always consisted of assumption checking, descriptive statistics, analyses of variance and post-hoc tests where appropriate. This process of data entry and analysis became increasingly easier and less time consuming as the project continued.

One of the main challenges of this stage was the change of my supervisory team. This change meant that my supervisory team no longer contained an expert in the field of AoA and I needed to adapt to a different style of supervision. However, this also prompted me to become a more independent researcher and fully establish my own expertise in the field.

10.5.3 Years Five, Six and Seven

While the literature review, Chapter 4 and Chapter 5 were drafted during the earlier stages of the PhD, the most important milestones of this stage included maintaining these chapters, collecting the remaining data, interpreting the findings and writing Chapters 5-8. Due to the original experimental chapters repeating some of the methodological information across studies, I made the decision to include a general methodology chapter (Chapter 2) after consultation with my supervisory team. This enhanced the structure and format of the thesis and reduced repetition.

Completing the data collection and analyses enabled me to contextualise the results obtained across the experimental paradigms reported in this thesis with reference to existing literature and the key theories discussed in Chapter 1. This was particularly salient while completing and reporting the comparison of AoA effect sizes in Chapter 9. Indeed, despite designing and implementing a systematic, multi-task investigation with the intention of comparing and contrasting effect sizes across experimental paradigms, each individual study was initially conducted and reported in isolation. This meant that while I could begin to see patterns emerging in the data, the critical interpretation of the findings could not be completed until all of the data were collected and analysed. This was accomplished through extensive cross referencing and immersion in the data during a writing retreat to minimise potential distractions.

Chapter 3 (perceptual identification) and Chapter 8 (delayed picture naming) were introduced following the completion of the viva voce. The perceptual identification study was introduced to ensure that the effects of AoA during perceptual processing were fully explored. Indeed, although total fixation durations can indicate perceptual processing, prior to the inclusion of the perceptual identification study this thesis did not include a purely perceptual task. Experiment 1a revealed significant effects of AoA on VDTs, decision times and error/omission rates during perceptual identification. In contrast, Experiment 1b revealed null-effects of word frequency during this task. These findings provided stronger support for a perceptual locus – or loci – of AoA than was previously possible when only consulting total fixation duration.

The delayed picture naming study was introduced to ensure that the stimuli sets employed throughout this programme of research were not susceptible to the confounding effects of initial phoneme. Indeed, if initial phoneme confounded the original results, the findings reported for the experiments which required a verbal response (Experiments 4a, 4b, 5a and 5b) may have been unreliable. However, Experiments 6a and 6b revealed that there were no significant effects during delayed picture naming. This demonstrated that the findings which were reported for immediate picture naming and immediate word reading were not confounded by difficulties in initiating articulation. Consequently, the inclusion of the perceptual identification study and the delayed picture naming study strengthened the conclusions which could be drawn from this programme of research.

Completing the thesis has taught me that in order to produce valid, reliable and original contributions to knowledge researchers must frequently follow a longitudinal approach in which insights emerge gradually as the research progresses. Indeed, throughout this process I took modest and realistic steps towards meeting the aims and objectives and progress was often slow and staggered. However, it has also taught me that the literature, researcher and programme of research change considerably over the time course of completing a part-time PhD. Indeed, this often meant that I needed to adopt a pragmatic approach to respond to these changes effectively while also keeping my focus. The process of completing this PhD has also enabled me to develop expertise in AoA and quantitative research in addition to expanding my broader abilities to design, implement and evaluate a large programme of research. As such, it has provided me with the skills and confidence to work as a competitive and independent researcher.

10.6 Chapter Conclusion

This chapter has summarised how this programme of research has presented a number of significant contributions to knowledge concerning the loci and nature of AoA effects. Indeed, using a systematic, controlled, multi-task investigation which combined adaptations of contemporary experimental paradigms and eye-tracking, this thesis lends substantial support for the multi-loci perspective of AoA effects in this thesis (Ellis, Holmes, & Wright, 2010; Ellis & Lambon Ralph, 2000; Izura & Ellis, 2002, 2004; Lake & Cottrell, 2005; Lambon Ralph & Ehsan, 2006; Stewart & Ellis, 2008).

For example, two distinct and prominent loci of AoA effects emerged during this programme of research; with a moderate locus occurring between perceptual/structural and semantic processing and a stronger locus occurring between semantic and lexical processing. This finding also supports the findings of Catling and Johnston (2009), who observed a similar pattern of AoA effects when employing a multi-task investigation of AoA. However, this programme of research expands these insights due to rigorous control of extraneous variables and explicit comparison of the effect sizes of AoA across experimental paradigms. Furthermore, the dissociation between the effects of AoA during indirect lexical access (i.e. picture naming) and direct lexical access (i.e. word reading) lends substantial support to the multi-loci prediction that arbitrary mapping between levels of processing elicits stronger AoA effects than those observed in tasks which involve transparent mapping between levels of processing (Ellis, Holmes, & Wright, 2010; Ellis & Lambon Ralph, 2000; Stewart & Ellis, 2008).

In addition to these insights, it is also notable that word frequency did not exert a significant or consistent effect on response times, total fixation durations or error/omission rates when AoA and a variety of other influential psycholinguistic properties were controlled. This demonstrates that AoA, rather than word frequency, influenced performance during the tasks reported in this thesis. Furthermore, it offers additional support to the multi-loci perspective, which predicts that AoA exerts particularly prominent effects when word frequency and other psycholinguistic properties are controlled (Brysbaert & Ghyselinck, 2006; Izura & Ellis, 2002, 2004; Lake & Cottrell, 2005; Lambon Ralph & Ehsan, 2006; Lewis, 2006; Stewart & Ellis, 2008).

This thesis has also presented a number of methodological adaptations which can improve the validity and reliability of future AoA research (Lewis, 2006; Zevin & Seidenberg, 2002, 2004). This included the design and implementation of rigorously controlled, semi-factorial AoA and word frequency stimuli sets. This is a particularly useful contribution due to facilitating greater experimental control than non-factorial stimuli sets or semi-factorial stimuli sets which have not controlled the same spectrum of psycholinguistic properties. It is also a larger and more representative collection of materials than the fully-factorial stimuli sets which are occasionally used in previous studies (Brysbaert & New, 2009; Chalard et al., 2003; Cortese & Khanna, 2007; Johnston & Barry, 2006; Lewis, 2006; Juhasz & Rayner, 2003, 2006; Zevin & Seidenberg, 2002, 2004). Indeed, the stimuli sets developed during this thesis elicited a consistent pattern of results across experimental paradigms, suggesting that they are valid and reliable materials. Full stimuli set characteristics are presented in Appendix A and Appendix B.

This programme of research also included a synthesis of adapted contemporary experimental paradigms and eye-tracking. This enabled the researcher to assess the multi-loci principles by gradually increasing the processing demands required for successful task completion while also obtaining time-sensitive measures. Indeed, while Juhasz and Rayner (2006) demonstrated that AoA exerted significant effects on gaze fixations during sentence reading, this approach had not yet been extended to other experimental paradigms or to pictorial stimuli sets. Therefore, eye-movements were monitored across all of the experimental paradigms reported in this thesis to ascertain whether AoA influenced perceptual processing speed during all of these tasks. This enabled the researcher to demonstrate that AoA did indeed influence perceptual processing speed during picture-category verification/falsification, picture-name verification/falsification, picture naming and word reading. Furthermore, it also enabled the researcher to demonstrate that AoA influenced processing speed when participants viewed both pictorial and textual materials. Consequently, this programme of research presented novel insights into the consistent and strong AoA effects on perceptual processing speed across experimental paradigms.

Several implications can be drawn from the findings reported in this thesis. Firstly, contrary to the assertions of Zevin and Seidenberg (2002, 2004), AoA is an independent, valid and reliable variable which is not reducible to the potentially confounding effects of word frequency, imageability, concreteness, familiarity, name agreement or word length. This critique of AoA research is redundant when researchers control these variables during the construction of stimuli sets. Secondly, rigorous multi-task investigations can provide valuable insights into the nature and loci of the effects exerted by psycholinguistic properties such as AoA and word frequency. Indeed, by incorporating a variety of tasks which assessed different levels of cognitive processing, this programme of research enabled the researcher to examine the loci and nature of AoA and word frequency in a comprehensive and systematic manner. Furthermore, by ensuring that methodological elements were consistent across experimental paradigms, this enabled the researcher to standardise data at the time of collection rather than during data analyses. This facilitated the comparison of effect sizes across different experimental paradigms and levels of processing in accordance with the multi-loci perspective of AoA effects.

A third implication is that AoA exerts significant influences on perceptual processing, semantic processing, indirect lexical access, direct lexical access and articulation. Indeed, AoA exerted significant and prominent effect on manual response times, verbal response times and total fixation durations across all of the tasks reported in this thesis. Furthermore, the strongest locus of AoA effects was detected between semantic and lexical processing while a second and less pronounced locus was detected between perceptual/structural and semantic processing.

The final implication of these findings is that the multi-loci perspective of AoA is currently the only theoretical perspective which can account for this pattern of results. Indeed, AoA exerts significant effects on perceptual, semantic and lexical processing speeds as assessed by the experimental paradigms reported in this thesis. Rather than one prominent, localised effect of AoA emerging from the results of these experiments, at least two distinct loci have been observed between levels of processing. This is inconsistent with the theoretical models which adopt a localist perspective but it lends substantial support to the multi-loci perspective.

10.7 Concluding Statement

Based on the critical consideration of the literature presented in Chapter 1, the data reported in the experimental chapters and the interpretation of the findings reported throughout this thesis, it can be concluded that AoA exerts significant and pervasive effects on cognitive processing, there are multiple loci of AoA effects dispersed throughout the cognitive system and that these effects are not reducible to those of other psycholinguistic properties.

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12. Appendices

Appendix A: AoA Stimuli Set Characteristics

Table A.1 AoA and word frequency values for earlier and later acquired stimuli

Item	AoA Set	Category Assigned	Objective AoA (Months)	Objective AoA (75%)	Rated AoA (7 point scale)	Rated AoA (months)	Celex (Combined)	Rated Frequency	Kučera-Francis frequency
sock	Early	Manmade	15.30	23.40	1.65	23.40	3.00	4.05	4.00
carrot	Early	Natural	22.70	25.10	2.25	42.00	3.00	3.40	1.00
scissors	Early	Manmade	26.30	23.40	2.50	48.00	4.00	3.45	1.00
squirrel	Early	Natural	20.00	25.10	2.45	46.80	4.00	2.20	1.00
frog	Early	Natural		23.40	2.10	38.40	4.00	2.25	1.00
spider	Early	Natural		25.10	1.75	27.00	4.00	3.05	2.00
duck	Early	Natural		22.10	1.70	25.20	4.00	3.50	9.00
banana	Early	Natural		23.40	1.70	25.20	4.00	3.70	4.00
butterfly	Early	Natural		23.40	2.30	43.20	5.00	2.55	2.00
boot	Early	Manmade	15.20	23.40	1.90	32.40	8.00	4.14	13.00
candle	Early	Manmade	23.80	38.50	3.25	66.00	8.00	3.50	18.00
airplane	Early	Manmade		23.40	2.25	42.00	8.00	3.10	11.00
mouse	Early	Natural		23.40	1.95	34.20	8.00	2.30	10.00
flag	Early	Man made	28.40	38.50	2.80	55.20	9.00	2.15	16.00
monkey	Early	Natural		25.10	2.30	43.20	9.00	2.10	9.00
spoon	Early	Manmade		22.10	1.45	16.20	11.00	4.05	6.00
rabbit	Early	Natural		22.10	1.90	32.40	11.00	2.80	11.00
brush	Early	Manmade		23.40	2.10	38.40	12.00	3.45	44.00
elephant	Early	Natural	15.80	23.40	2.30	43.20	12.00	2.10	7.00
shoe	Early	Manmade		22.10	1.30	12.00	14.00	4.25	14.00
apple	Early	Natural	18.40	22.10	1.80	28.80	18.00	3.90	5.53
cake	Early	Manmade		23.40	1.80	28.80	21.00	3.40	13.00
pipe	Early	Manmade	66.60	74.50	3.35	68.40	22.00	2.05	20.00

cow	Early	Natural	15.30	23.40	1.45	16.20	22.00	2.90	29.00
wheel	Early	Manmade		25.10	2.10	38.40	28.00	2.95	56.00
clock	Early	Manmade		22.10	1.95	34.20	36.00	3.85	20.00
box	Early	Manmade	30.00	38.50	1.90	32.40	39.00	3.65	70.00
cat	Early	Natural	24.40	23.40	1.15	12.00	41.00	3.40	23.00
cigarette	Early	Manmade	64.80	86.50	3.25	66.00	49.00	3.30	25.00
leg	Early	Natural	31.40	38.50	1.45	16.20	63.00	3.70	58.00
train	Early	Manmade	19.10	25.10	2.00	36.00	68.00	3.05	
dog	Early	Natural		22.10	1.30	12.00	69.00	3.50	75.00
key	Early	Manmade	15.10	23.40	2.40	45.60	70.00	4.70	88.00
fish	Early	Natural		22.10	1.90	32.40	80.00	3.05	35.00
snail	Late	Natural	31.80	44.50	2.65	51.60	3.00	2.10	1.00
violin	Late	Manmade	56.90	62.50	3.20	64.80	4.00	2.15	11.00
ant	Late	Natural	57.10	62.50	2.30	43.20	4.00	2.50	6.00
tiger	Late	Natural	35.00	44.50	2.45	46.80	4.00	2.20	7.00
glove	Late	Manmade	34.80	44.50	2.40	45.60	5.00	2.75	9.00
trumpet	Late	Manmade	51.60	56.50	3.15	63.60	5.00	1.90	57.00
cherry	Late	Natural	67.30	74.50	2.70	52.80	6.00	2.75	6.00
deer	Late	Natural	63.00	86.50	2.55	49.20	6.00	1.90	13.00
bear	Late	Natural	33.90	50.50	1.85	30.60	6.00	2.60	57.00
leopard	Late	Natural	58.10	68.50	3.25	66.00	7.00	1.55	
bee	Late	Natural	43.90	56.50	1.95	34.20	7.00	2.85	11.00
drum	Late	Manmade	37.60	50.50	1.95	34.20	7.00	2.35	11.00
tomato	Late	Natural	48.20	68.50	2.20	40.80	7.00	3.75	4.00
ruler	Late	Manmade	54.60	62.50	2.75	54.00	8.00	3.10	3.00
grapes	Late	Natural	41.90	56.50	2.70	52.80	8.00	3.05	7.00
lorry	Late	Manmade	29.30	44.50	2.20	40.80	8.00	2.80	
onion	Late	Natural	52.10	68.50	2.55	49.20	9.00	3.45	15.00
potato	Late	Natural	62.30	74.50	2.00	36.00	11.00	3.90	15.00
kettle	Late	Manmade	33.00	44.50	2.45	46.80	11.00	4.45	3.00
goat	Late	Natural	47.90	56.50	2.45	46.80	12.00	2.00	6.00
fly	Late	Natural	44.30	56.50	2.15	39.60	17.00	3.10	33.00
tie	Late	Manmade	44.50	56.50	2.45	46.80	19.00	2.90	23.00

pen	Late	Manmade	32.90	44.50	2.00	36.00	19.00	4.45	18.00
skirt	Late	Manmade	42.40	56.50	2.00	36.00	20.00	3.30	21.00
sheep	Late	Natural	28.70	44.50	1.70	25.20	20.00	2.80	23.00
lamp	Late	Manmade	52.00	74.50	2.85	56.40	21.00	3.55	18.00
pan	Late	Manmade	27.70	44.50	2.35	44.40	22.00	3.90	
bell	Late	Manmade	33.00	44.50	2.20	40.80	27.00	2.50	18.00
cloud	Late	Natural	38.00	56.50	1.90	32.40	30.00	3.35	28.00
jacket	Late	Manmade	54.50	56.50	2.60	50.40	34.00	3.60	33.00
shirt	Late	Manmade	46.30	56.50	2.45	46.80	45.00	3.75	27.00
mountain	Late	Natural	52.10	62.50	2.70	52.80	46.00	2.30	33.00
ring	Late	Manmade	43.50	50.50	2.50	48.00	66.00	3.45	47.00
desk	Late	Manmade	68.90	86.50	2.80	55.20	82.00	3.60	65.00

Table A.2 Additional properties of earlier and later acquired stimuli

Item	AoA Set	Familiarity	Density[×]	Visual Complexity	Imageability	Picture-Name Agreement	Category Typicality*	Concreteness	Letters	Syllables	Phonemes
Sock	Early	4.73	13.00	1.80	6.20	7.00	1.33	581.00	4.00	3.00	1.00
carrot	Early	4.23	7.00	2.33	6.50	6.50	7.00	622.00	5.00	5.00	2.00
scissors	Early	3.91	0.00	2.40	6.20	6.11	1.00	596.00	8.00	5.00	2.00
squirrel	Early	2.55	0.00	3.80	6.30	6.70	6.80	612.00	7.00	6.00	2.00
frog	Early	2.38	8.00	3.30	6.35	6.50	6.20	619.00	4.00	4.00	1.00
spider	Early	3.09	4.00	3.90	6.45	7.00	6.00	607.00	6.00	5.00	2.00
duck	Early	2.59	15.00	3.10	6.55	6.80	6.80	606.00	4.00	3.00	1.00
banana	Early	3.71	0.00	1.40	6.55	6.40	7.00	633.00	6.00	6.00	3.00
butterfly	Early	2.73	0.00	4.20	6.25	6.60	7.00	593.00	9.00	7.00	3.00
boot	Early	4.23	19.00	2.45	6.05	6.60	1.10	595.00	4.00	3.00	1.00
candle	Early	3.32	6.00	2.90	6.10	6.40	1.70	565.00	6.00	5.00	2.00
airplane	Early	2.75		4.11	6.55	6.20	1.00	535.00	8.00	7.00	3.00
mouse	Early	2.59	11.00	2.80	6.65	6.60	6.50	624.00	5.00	3.00	1.00
flag	Early	2.22	11.00	1.50	6.35	6.80	1.30	606.00	4.00	4.00	1.00
monkey	Early	2.09	2.00	2.89	6.45	6.30	6.50	566.00	6.00	5.00	2.00
spoon	Early	4.64	7.00	1.50	6.30	6.80	1.20	614.00	5.00	4.00	1.00
rabbit	Early	2.81	3.00	3.30	6.60	6.89	6.80	635.00	6.00	5.00	2.00
brush	Early	3.68	5.00	2.70	6.20	6.10	1.50	589.00	5.00	4.00	1.00
elephant	Early	2.20		2.40	6.70	6.90	6.50	628.00	8.00	7.00	3.00
shoe	Early	4.68	7.00	1.89	6.40	6.80	2.00	600.00	4.00	2.00	1.00
apple	Early	4.48	2.00	1.80	6.50	5.86	6.25	620.00	5.00	3.00	2.00
cake	Early	3.32	21.00	2.80	6.40	6.30	2.10	624.00	4.00	3.00	1.00
pipe	Early	2.20	14.00	2.50	5.65	6.89	1.40	602.00	4.00	3.00	1.00
cow	Early	3.18	27.00	3.70	6.55	6.56	6.40	621.00	3.00	2.00	1.00
wheel	Early	2.68	4.00	1.89	6.45	6.30	1.22	573.00	5.00	3.00	1.00
clock	Early	4.18	10.00	2.80	6.25	7.00	1.30	591.00	5.00	4.00	1.00
box	Early	3.64	17.00	1.90	5.60	6.50	1.13	597.00	3.00	4.00	1.00
cat	Early	4.00	29.00	3.67	6.40	6.70	6.40	615.00	3.00	3.00	1.00
cigarette	Early	3.86	0.00	2.20	6.25	6.45	1.30	607.00	9.00	7.00	3.00

leg	Early	4.73	19.00	3.90	6.05	6.63	6.00	626.00	3.00	3.00	1.00
train	Early	3.64	7.00	4.50	6.25	6.70	1.00	592.00	5.00	4.00	1.00
dog	Early	4.05	23.00	3.22	6.65	6.80	7.00	610.00	3.00	3.00	1.00
key	Early	4.68	15.00	2.50	6.25	6.80	1.10	612.00	3.00	2.00	1.00
fish	Early	3.09	10.00	3.10	6.75	6.60	6.90	597.00	4.00	3.00	1.00
snail	Late	2.45	3.00	3.60	6.25	6.60	6.90	579.00	5.00	4.00	1.00
violin	Late	2.14	2.00	3.40	6.40	6.80	1.33	626.00	5.00	6.00	3.00
ant	Late	2.75	11.00	2.70	5.90	6.70	6.80	604.00	3.00	3.00	1.00
tiger	Late	1.77	5.00	4.20	6.60	6.40	6.89	611.00	5.00	4.00	2.00
glove	Late	2.91	7.00	2.40	5.95	6.70	1.30	607.00	5.00	4.00	1.00
trumpet	Late	2.05	1.00	3.50	6.40	6.80	1.40	608.00	7.00	7.00	2.00
cherry	Late	2.43		1.70	6.25	6.40	7.00	611.00	6.00	4.00	2.00
deer	Late	1.73	19.00	3.56	6.25	6.60	6.60	631.00	4.00	2.00	1.00
bear	Late	1.73	23.00	3.50	6.40	6.80	5.50	585.00	4.00	2.00	1.00
leopard	Late	2.00	1.00	4.60	6.15	6.30	6.67	595.00	7.00	5.00	2.00
bee	Late	2.82		3.60	6.30	6.50	6.00	597.00	3.00	2.00	1.00
drum	Late	2.41	7.00	4.70	6.45	6.30	1.60	602.00	4.00	4.00	1.00
tomato	Late	3.64		2.10	6.45	6.10	6.63	662.00	6.00	6.00	3.00
ruler	Late	3.82	0.00	2.00	5.75	6.56	1.10	555.00	5.00	4.00	2.00
grapes	Late	3.00	15.00	3.40	6.25	6.50	7.00	611.00	6.00	5.00	1.00
lorry	Late	3.41	5.00	4.10	6.30	6.67	1.00	420.00	5.00	4.00	2.00
onion	Late	3.95		2.80	6.20	6.60	7.00	632.00	5.00	5.00	2.00
potato	Late	3.91		1.90	6.20	6.50	6.30	629.00	6.00	6.00	3.00
kettle	Late	4.59	7.00	2.20	6.25	6.22	1.60	602.00	6.00	4.00	2.00
goat	Late	2.00	11.00	3.10	6.30	6.80	6.78	636.00	4.00	3.00	1.00
fly	Late	3.23	10.00	3.90	5.60	6.50	6.90	525.00	3.00	3.00	1.00
tie	Late	2.91	18.00	1.78	6.10	7.00	1.10	568.00	3.00	2.00	1.00
pen	Late	4.64	25.00	1.90	6.35	6.30	1.20	571.00	3.00	3.00	1.00
skirt	Late	3.55	4.00	2.80	6.05	6.20	1.60	614.00	5.00	4.00	1.00
sheep	Late	2.86	9.00	2.60	6.40	6.60	6.50	622.00	5.00	3.00	1.00
lamp	Late	3.73	15.00	2.88	6.00	6.40	1.30	615.00	4.00	4.00	1.00
pan	Late	4.70	28.00	1.78	6.70	6.30	1.33	586.00	3.00	3.00	1.00
bell	Late	2.50	19.00	2.30	6.60	6.89	1.10	620.00	4.00	3.00	1.00

cloud	Late	4.05	3.00	2.22	6.60	6.60	6.80	554.00	5.00	4.00	1.00
jacket	Late	4.12		3.30	5.95	6.20	1.50	635.00	6.00	5.00	2.00
shirt	Late	4.09	8.00	2.11	6.30	6.50	1.30	616.00	5.00	3.00	1.00
mountain	Late	2.41	1.00	2.90	6.65	6.30	6.89	616.00	8.00	6.00	2.00
ring	Late	3.82		2.10	5.95	6.80	1.20	593.00	4.00	3.00	1.00
desk	Late	4.60	5.00	3.30	6.15	5.90	1.40	583.00	4.00	4.00	1.00

Note. ˟ Orthographic neighbourhood density

* A higher score denotes a more natural item while a lower score denotes a more artificial (i.e. manmade) item

Appendix B: Word Frequency Stimuli Set Characteristics

Table B.1 Word frequency and AoA values for low and high frequency stimuli

Item	Frequency Set	Category Assigned	Objective AoA (Months)	Objective AoA (75%)	Rated AoA (7 point scale)	Rated AoA (months)	Celex (Combined)	Rated Frequency	Kučera-Francis frequency
Ant	Low	Natural	57.10	62.50	2.30	43.20	4.00	2.50	6.00
arrow	Low	Manmade	54.10	62.50	2.85	56.40	8.00	2.20	
ball	High	Manmade		23.40	1.25	12.00	93.00	3.54	110.00
balloon	Low	Manmade	14.00	22.10	1.80	28.80	3.00	2.90	10.00
banana	Low	Natural		23.40	1.70	25.20	4.00	3.70	4.00
bear	Low	Natural	33.90	50.50	1.85	30.60	6.00	2.60	57.00
bee	Low	Natural	43.90	56.50	1.95	34.20	7.00	2.85	11.00
bell	High	Manmade	33.00	44.50	2.20	40.80	27.00	2.50	18.00
belt	High	Manmade	38.80	50.50	2.80	55.20	2.00	3.20	29.00
boat	High	Manmade		23.40	1.85	30.60	56.00	3.30	
box	High	Manmade	30.00	38.50	1.90	32.40	39.00	3.65	70.00
broom	Low	Manmade	71.90	86.50	3.05	61.20	6.00	2.15	2.00
butterfly	Low	Natural		23.40	2.30	43.20	5.00	2.55	2.00
carrot	Low	Natural	22.70	25.10	2.25	42.00	3.00	3.40	1.00
cat	High	Natural	24.40	23.40	1.15	12.00	41.00	3.40	23.00
cigarette	High	Manmade	64.80	86.50	3.25	66.00	49.00	3.30	25.00
cloud	High	Natural	38.00	56.50	1.90	32.40	30.00	3.35	28.00
cooker	Low	Manmade	42.90	56.50	2.35	44.40	4.00	4.00	
cow	High	Natural	15.30	23.40	1.45	16.20	22.00	2.90	29.00
deer	Low	Natural	63.00	86.50	2.55	49.20	6.00	1.90	13.00
desk	High	Manmade	68.90	86.50	2.80	55.20	82.00	3.60	65.00
dog	High	Natural		22.10	1.30	12.00	69.00	3.50	75.00
drum	Low	Manmade	37.60	50.50	1.95	34.20	7.00	2.35	11.00

duck	Low	Natural		22.10	1.70	25.20	4.00	3.50	9.00
elephant	High	Natural	15.80	23.40	2.30	43.20	12.00	2.10	7.00
envelope	High	Manmade	57.40	68.50	3.25	66.00	19.00	3.15	21.00
fence	High	Manmade	46.30	62.50	2.25	42.00	22.00	2.40	30.00
finger	High	Natural	18.40	23.40	1.50	18.00	48.00	3.35	40.00
fish	High	Natural		22.10	1.90	32.40	80.00	3.05	35.00
foot	High	Natural	14.80	38.50	1.50	18.00	98.00	3.50	70.00
fork	Low	Manmade		23.40	1.95	34.20	12.00	4.00	14.00
frog	Low	Natural		23.40	2.10	38.40	4.00	2.25	1.00
glasses	High	Manmade		23.40	2.40	45.60	32.00	3.85	29.00
goat	High	Natural	47.90	56.50	2.45	46.80	12.00	2.00	6.00
gun	High	Manmade	35.80	44.50	2.75	54.00	63.00	2.35	118.00
hat	High	Manmade		23.40	1.65	23.40	53.00	2.90	56.00
horse	High	Natural		23.40	1.75	27.00	85.00	2.75	117.00
iron	High	Manmade	35.40	44.50	3.10	62.40	68.00	3.05	43.00
jacket	High	Manmade	54.50	56.50	2.60	50.40	34.00	3.60	33.00
kettle	Low	Manmade	33.00	44.50	2.45	46.80	11.00	4.45	3.00
knife	High	Manmade	17.40	23.40	2.15	39.60	35.00	4.30	76.00
leaf	High	Natural	21.60	25.10	2.15	39.60	15.00	3.05	12.00
lorry	Low	Manmade	29.30	44.50	2.20	40.80	8.00	2.80	
moon	High	Natural	25.60	25.10	1.95	34.20	53.00	3.00	60.00
mountain	High	Natural	52.10	62.50	2.70	52.80	46.00	2.30	33.00
onion	Low	Natural	52.10	68.50	2.55	49.20	9.00	3.45	15.00
orange	High	Natural	26.80	38.50	1.70	25.20	27.00	3.45	23.00
pear	Low	Natural	33.20	44.50	2.40	45.60	2.00	2.95	6.00
peg	Low	Manmade	33.30	44.50	2.40	45.60	4.00	2.60	
pen	Low	Manmade	32.90	44.50	2.00	36.00	19.00	4.45	18.00
penguin	Low	Natural	29.20	38.50	2.35	44.40	4.00	2.00	
plug	Low	Manmade	51.70	68.50	2.85	56.40	6.00	3.20	23.00
pram	Low	Manmade	23.10	38.50	2.15	39.60	5.00	2.10	
rabbit	Low	Natural		22.10	1.90	32.40	11.00	2.80	11.00
ruler	Low	Manmade	54.60	62.50	2.75	54.00	8.00	3.10	3.00
scissors	Low	Manmade	26.30	23.40	2.50	48.00	4.00	3.45	1.00

screw	Low	Manmade	64.30	80.50	2.95	58.80	7.00	2.65	21.00
sheep	High	Natural	28.70	44.50	1.70	25.20	20.00	2.80	23.00
snail	Low	Natural	31.80	44.50	2.65	51.60	3.00	2.10	1.00
snake	High	Natural	14.20	25.10	1.95	34.20	14.00	2.30	44.00
sock	Low	Manmade	15.30	23.40	1.65	23.40	3.00	4.05	4.00
spider	Low	Natural		25.10	1.75	27.00	4.00	3.05	2.00
spoon	Low	Manmade		22.10	1.45	16.20	11.00	4.05	6.00
swan	Low	Natural	48.20	62.50	2.90	57.60	5.00	2.45	3.00
thumb	High	Natural	35.30	38.50	2.00	36.00	22.00	3.10	10.00
tiger	Low	Natural	35.00	44.50	2.45	46.80	4.00	2.20	7.00
watch	High	Manmade	33.70	38.50	2.25	42.00	37.00	4.10	81.00
wheel	High	Manmade		25.10	2.10	38.40	28.00	2.95	56.00

Table B.2 Additional properties of low and high frequency stimuli

Item	Frequency Set	Familiarity	Density[×]	Visual Complexity	Imageability	Picture-Name Agreement	Category Typicality*	Concreteness	Letters	Syllables	Phonemes
Ant	Low	2.75	11.00	2.70	5.90	6.70	6.80	604.00	3.00	1.00	3.00
arrow	Low	3.27	0.00	1.10	6.30	6.90	1.60	595.00	5.00	2.00	3.00
ball	High	3.36	19.00	3.20	6.40	6.60	1.40	615.00	4.00	1.00	3.00
balloon	Low	2.86	2.00	1.67	6.55	6.80	1.67	623.00	7.00	2.00	5.00
banana	Low	3.71	0.00	1.40	6.55	6.40	7.00	633.00	6.00	3.00	6.00
bear	Low	1.73	23.00	3.50	6.40	6.80	5.50	585.00	4.00	1.00	2.00
bee	Low	2.82		3.60	6.30	6.50	6.00	597.00	3.00	1.00	2.00
bell	High	2.50	19.00	2.30	6.60	6.89	1.10	620.00	4.00	1.00	3.00
belt	High	3.81	15.00	1.89	5.80	6.00	1.80	602.00	4.00	1.00	4.00
boat	High	4.00		3.56	6.30	6.44	1.22		4.00	1.00	3.00
box	High	3.64	17.00	1.90	5.60	6.50	1.13	597.00	3.00	1.00	4.00
broom	Low	2.73	5.00	1.89	6.30	6.88	1.25	613.00	5.00	1.00	4.00
butterfly	Low	2.73	0.00	4.20	6.25	6.60	7.00	593.00	9.00	3.00	7.00
carrot	Low	4.23	7.00	2.33	6.50	6.50	7.00	622.00	6.00	2.00	5.00
cat	High	4.00	29.00	3.67	6.40	6.70	6.40	615.00	3.00	1.00	3.00
cigarette	High	3.86	0.00	2.20	6.25	6.45	1.30	607.00	9.00	3.00	7.00
cloud	High	4.05	3.00	2.22	6.60	6.60	6.80	554.00	5.00	1.00	4.00
cooker	Low	4.45	10.00	2.75	5.85	6.78	1.10		6.00	2.00	4.00
cow	High	3.18	27.00	3.70	6.55	6.56	6.40	621.00	3.00	1.00	2.00
deer	Low	1.73	19.00	3.56	6.25	6.60	6.60	631.00	4.00	1.00	2.00
desk	High	4.60	5.00	3.30	6.15	5.90	1.40	583.00	4.00	1.00	4.00
dog	High	4.05	23.00	3.22	6.65	6.80	7.00	610.00	3.00	1.00	3.00
drum	Low	2.41	7.00	4.70	6.45	6.30	1.60	602.00	4.00	1.00	4.00
duck	Low	2.59	15.00	3.10	6.55	6.80	6.80	606.00	4.00	1.00	3.00
elephant	High	2.20		2.40	6.70	6.90	6.50	628.00	8.00	3.00	7.00
envelope	High	4.30	0.00	1.14	5.80	6.90	2.00	579.00	8.00	3.00	7.00
fence	High	2.68	2.00	2.20	5.95	6.70	2.00	597.00	5.00	1.00	4.00
finger	High	4.68	9.00	2.20	6.05	6.90	6.22		6.00	2.00	5.00

fish	High	3.09	10.00	3.10	6.75	6.60	6.90	597.00	4.00	1.00	3.00
foot	High	4.59	14.00	2.80	5.90	6.80	5.80	558.00	4.00	1.00	3.00
fork	Low	4.55	10.00	2.60	6.35	6.10	1.30	592.00	4.00	1.00	3.00
frog	Low	2.38	8.00	3.30	6.35	6.50	6.20	619.00	4.00	1.00	4.00
glasses	High	3.82	0.00	2.40	6.25	6.80	1.00		7.00	2.00	6.00
goat	High	2.00	11.00	3.10	6.30	6.80	6.78	636.00	4.00	1.00	3.00
gun	High	2.00	22.00	3.80	6.50	6.45	1.13	612.00	3.00	1.00	3.00
hat	High	2.59	29.00	1.70	6.60	6.70	1.56	601.00	3.00	1.00	3.00
horse	High	2.82	14.00	3.60	6.70	6.40	6.45	613.00	5.00	1.00	3.00
iron	High	3.05		3.40	5.80	6.90	1.11	584.00	4.00	1.00	3.00
jacket	High	4.12		3.30	5.95	6.20	1.50	635.00	6.00	2.00	5.00
kettle	Low	4.59	7.00	2.20	6.25	6.22	1.60	602.00	6.00	2.00	4.00
knife	High	4.82	1.00	1.13	6.45	6.70	1.22	612.00	5.00	1.00	3.00
leaf	High	3.41	12.00	3.60	6.45	6.50	6.90	593.00	4.00	1.00	3.00
lorry	Low	3.41	5.00	4.10	6.30	6.67	1.00	420.00	5.00	2.00	4.00
moon	High	3.32	17.00	1.10	6.65	6.00	6.50	581.00	4.00	1.00	3.00
mountain	High	2.41	1.00	2.90	6.65	6.30	6.89	616.00	8.00	2.00	6.00
onion	Low	3.95		2.80	6.20	6.60	7.00	632.00	5.00	2.00	5.00
orange	High	3.73		2.33	6.55	6.89	6.70	601.00	6.00	2.00	5.00
pear	Low	3.23	20.00	1.80	6.15	6.40	7.00	634.00	4.00	1.00	2.00
peg	Low	3.35	17.00	1.90	5.60	6.90	1.20	537.00	3.00	1.00	3.00
pen	Low	4.64	25.00	1.90	6.35	6.30	1.20	571.00	3.00	1.00	3.00
penguin	Low	1.86	1.00	2.70	6.55	6.67	6.80		7.00	2.00	7.00
plug	Low	3.59	3.00	2.50	5.70	6.22	1.10	558.00	4.00	1.00	4.00
pram	Low	2.40	8.00	3.00	5.80	6.50	1.20		4.00	1.00	4.00
rabbit	Low	2.81	3.00	3.30	6.60	6.89	6.80	635.00	6.00	2.00	5.00
ruler	Low	3.82	0.00	2.00	5.75	6.56	1.10	555.00	5.00	2.00	4.00
scissors	Low	3.91	0.00	2.40	6.20	6.11	1.00	596.00	8.00	2.00	5.00
screw	Low	2.77	6.00	2.60	5.80	6.00	1.20		5.00	1.00	4.00
sheep	High	2.86	9.00	2.60	6.40	6.60	6.50	622.00	5.00	1.00	3.00
snail	Low	2.45	3.00	3.60	6.25	6.60	6.90	579.00	5.00	1.00	4.00
snake	High	2.05	7.00	4.00	6.70	6.90	6.33	621.00	5.00	1.00	4.00
sock	Low	4.73	13.00	1.80	6.20	7.00	1.33	581.00	4.00	1.00	3.00

spider	Low	3.09	4.00	3.90	6.45	7.00	6.00	607.00	6.00	2.00	5.00
spoon	Low	4.64	7.00	1.50	6.30	6.80	1.20	614.00	5.00	1.00	4.00
swan	Low	2.23	9.00	3.10	6.55	6.20	6.80		4.00	1.00	4.00
thumb	High	4.64	2.00	2.60	6.10	6.50	7.00	638.00	5.00	1.00	3.00
tiger	Low	1.77	5.00	4.20	6.60	6.40	6.89	611.00	5.00	2.00	4.00
watch	High	4.27	8.00	3.10	6.30	6.33	1.10	487.00	5.00	1.00	4.00
wheel	High	2.68	4.00	1.89	6.45	6.30	1.22	573.00	5.00	1.00	3.00

Note. ˣ Orthographic neighbourhood density

* A higher score denotes a more natural item while a lower score denotes a more artificial (i.e. manmade) item