The Impact of Age of Acquisition on Semantic Representations: An EEG Study

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Table of Contents

List of Figures and Tables

Abstract

The age of acquisition (AOA) of a word has a significant impact on how it is processed; words acquired earlier in life are processed more quickly and accurately than words acquired later. Previous behavioural research has also independently established that AOA affects semantic processing, and that electroencephalography (EEG) can be used to examine AOA effects. However, no study has examined AOA and semantic processing in tandem, nor have potential confounds between AOA and word frequency been considered. To disentangle these effects, the current study employs EEG to examine the interaction between AOA and concreteness, whilst controlling for and investigating word frequency. Data was obtained from 28 participants completing a lexical decision task. The results revealed a significant effect of concreteness on the N400 component of the event-related potential (ERP) when controlling for AOA. The impact of AOA on the N400 supports a relationship with semantic processing. Importantly, there was also an interaction between concreteness and AOA; however, only earlier acquired concrete words displayed an AOA effect. The ERPs for word frequency after controlling for AOA showed a similar pattern of differences to previous research, although no comparisons reached significance. This suggests the AOA results were not likely to be confounded by frequency. These findings contribute to the understanding of semantic processing and suggest that AOA and concreteness each have distinct effects on processing and also provide insight into how the lexical system is organised. Notably, the findings suggest that abstract and concrete words are learned differently early in life, but not later in life. These results assist in further specifying previous theories where differences between abstract and concrete words were hypothesised, but interactions across the lifespan were not considered.

Keywords: age of acquisition, semantic processing, electroencephalography study

Declaration

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Contributor Roles Table

Role	Role Description	Student	Supervisor 1	Supervisor 2
Conceptualisation	Ideas; formulation or evolution of overarching research goals and aims.	X		
Methodology	Development or design of methodology; creation of models.		X	
Project Administration	Management and coordination responsibility for the research activity planning and execution.	X		
Supervision	Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team.	X		
Resources	Provision of study material, laboratory samples, instrumentation, computing resources, or other analysis tools.		X	
Software	Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code.		X	
Investigation	Conducting research – specifically performing experiments, or data/evidence collection.	X		
Validation	Verification of the overall replication/reproducibility of results/experiments.	X		
Data Curation	Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later re-use.	X		
Formal Analysis	Application of statistical, mathematical, computational, or other formal techniques to analyse or synthesise study data.		X	
Visualisation	Visualisation/data presentation of the results.	X	X	
Writing – Original Draft	Specifically writing the initial draft.	X		
Writing – Review & Editing	Critical review, commentary or revision of original draft.	X	X	

The Impact of Age of Acquisition on Semantic Representations: An EEG Study

The acquisition and processing of words in the mental lexicon is a multifaceted and intricate process, influenced by numerous factors. Among these factors, age of acquisition, semantic processing, and word frequency play significant roles. Age of acquisition (AOA) is the particular age when an individual first learns a word. Research examining the relationship between AOA and the processing of words has found that words acquired at an earlier stage (early AOA words) are typically processed with greater speed and accuracy compared to words acquired later in life (late AOA words; Brysbaert & New, 2009). The processing advantage held by early AOA words can be attributed, in part, to the establishment of stronger semantic connections between these words and other concepts within the lexicon compared to late AOA words (Chang et al., 2019).

The establishment of these connections is thought to differ between early and late AOA words, as early AOA words tend to be learned in a more concrete and imageable way, whereas late AOA words are often learned through abstraction and inference (Gentner, 2006). This occurrence suggests that as individuals acquire words earlier in their linguistic development, they form networks of meanings and associations. Consequently, when encountering an early AOA word, the mind can more rapidly access and retrieve the interconnected semantic information, which facilitates faster and more accurate processing.

Another factor that may cause the differential processing speed and accuracy observed between early and late AOA words is the increased exposure and familiarity that early AOA words have (Stadthagen-Gonzalez & Davis, 2006). Existing research predominantly examines AOA-controlled word frequency by using measures taken at a particular point in time, such as norms derived from newspaper counts or web scraping (Kuperman et al., 2012). It is crucial to consider the fact that if a word is acquired earlier, even if it has the same frequency in regular speech, the extended period during which individuals would have had the opportunity to hear it means it would have been encountered significantly more times. This phenomenon is referred to as cumulative frequency. Given that simple frequency is a critical factor in reading research, the importance of cumulative frequency in addition to age of acquisition and concreteness would not be unexpected.

An additional factor that has historically been shown to affect the difficulty of reading words is semantics. This factor has also been hypothesised to differ between early and late AOA words. That is, even if two words seem to have relatively similar semantics (e.g., influenza vs. COVID), but one is learnt earlier than another, their processing may in fact differ. The most extreme version of this hypothesis suggests that age of acquisition and semantics are largely the same thing (Woollams et al., 2016). One problem with these hypotheses involves the definition of what semantics is. A simple definition is that it refers to the intricate process of activating and integrating the meaning of a word with other concepts and words within the mental lexicon (Tamminen & Gaskell, 2013), and as expected, these properties of words significantly influence their recognition and comprehension.

Given the complexities of understanding what semantics is, one way of examining the extent to which it may affect behaviour is to look at aspects of it that are well established and use them as markers of semantic processing. One of the most common markers is concreteness (Paivio et al., 1994), which refers to whether words are abstract in nature (e.g. honesty), or concrete (e.g. mug). Numerous studies have demonstrated that concrete words are processed with greater accuracy and speed compared to abstract words (Schwanenflugel & Stowe, 1989), and that they also evoke a different brain response (Wang et al., 2010).

There are two main theories that explain concreteness effects: the context availability theory and the dual coding theory (Jessen et al., 2000). The context availability theory proposes that it is easier to retrieve a contextual framework - the meaning of the word as intended by the context, the speakers' intention, the listener's expectations, and the surrounding environment - for concrete words such as 'mug', as opposed to abstract words like 'honesty'. This is because concrete words often have clear, tangible references that can be easily linked to specific experiences, objects, or situations. Alternatively, abstract words often represent complex concepts or emotions, making it more challenging to establish a contextual framework (Kousta et al., 2011).

The dual coding theory suggests that there are two representational systems by which words are processed: the verbal system and the imaginal system (Holcomb et al., 1999). Both abstract and concrete words activate the verbal system; however, concrete words are also linked to the imaginal system. The availability of the imaginal system to create representations for concrete words facilitates their processing, allowing for more efficient comprehension. In contrast, abstract words are processed more slowly due to the absence of representation in the imaginal system (Altarriba et al., 1999). The combined context-extended dual coding hypothesis suggests that both the availability of contextual information and the activation of the imaginal system contribute to the processing advantage observed for concrete words (Barber et al., 2013). This hypothesis provides a more comprehensive explanation of concreteness effects in word recognition than the context availability theory alone.

The differentiation between abstract and concrete words is a well-established phenomenon. However, the interpretation of relevant behavioural and neuroscientific data continues to be a subject of debate among researchers (Montefinese, 2019). Critically, one unaddressed factor is the effect of AOA in word processing. It is well established that children tend to acquire concrete words at earlier stages of development compared to abstract words. The difference in the time of acquisition brings forward the possibility that observed differences between concrete and abstract words might be confounded by age of acquisition effects. This necessitates research that controls for AOA, further supported by the fact that AOA has not typically been controlled for in previous studies (e.g. West & Holcomb, 2000). This means that choosing otherwise matched stimuli would lead to concrete words having a lower AOA than abstract words due to the correlation between concreteness and AOA.

In summary, previous research has consistently demonstrated the influential role of age of acquisition, semantic processing, and word frequency in the processing of words. However, the extent to which these factors play a role individually has been extensively debated. The present study aims to build upon this existing research to further understand the specific effects of these factors using electroencephalography (EEG). The primary goal is to understand the relationship between age of acquisition and semantic processing by examining event-related potentials (ERPs). ERPs enable us to pinpoint when in the processing time-course these relationships occur. Additionally, they allow a spatial topography of the electrical activity of the brain at any given time and can differentiate between distinct types of processing in a way that simple reaction times cannot. In this case, two processes that cause the same reaction time may show an entirely different pattern of brain behaviour.

Examining the role of age of acquisition using EEG allows for the analysis of specific components of the ERP, including the N250 and N400. The N250 component is a negative deflection in the event-related potential that occurs approximately 250-300 milliseconds after the presentation of a stimulus. The N250 plays an important role in the context of semantic processing, as it is has been found to be related to orthographic access (Dufau et al., 2015) and may be an influential factor in frequency and AOA. The N250 component has been demonstrated to be more negative-going for concrete words than for abstract words (Barber et al., 2013; West & Holcomb, 2000). However, ERP effects has also been found to be larger for words that are semantically related to existing knowledge and experiences, regardless of their level of concreteness (Ding et al., 2017). These contradicting results suggest that the N250 component may reflect semantic integration rather than concreteness or abstractness. This study will examine this component to compare the effect elicited by early AOA words versus late AOA words.

The N400 component is a well established indicator of semantic processing. The N400 is a negative deflection observed in the ERP, which typically occurs around 350-400 milliseconds after the presentation of a stimulus and has a central distribution on the scalp. The relationship between N400 amplitude and concreteness has been explored with concrete words showing a greater N400 response than abstract words. Typically, when someone reads concrete words, a more negative N400 is found than when they read abstract words, and this effect can continue into later components, known as Late Positive Components (LPCs). This study will therefore examine this ERP component and if the standard effect of concreteness it elicits (e.g. a larger N400 response to concrete words) still occurs when AOA is controlled.

The simple word frequency effect has also been examined a number of times (see Brysbaert et al., 2017 for a review). Recently, researchers used ERPs to examine frequency effects. Whilst there have been mixed findings examining frequency effects (Amsel, 2011), a recent study tried to resolve this issue by using a ‘mega’ design with very large number of items and participants (Dufau et al., 2015). The results of this study are therefore likely to be more reliable than previous studies. The results found showed early frequency effects with a posterior distribution (around 100-150 ms), while later effects were evident in the frontal electrodes. These distributions were followed by a longer sustained effect (after 380 ms) in posterior electrodes.

Cumulative frequency effects have also been observed in language processing. Studies have shown that the N400 component decreases in amplitude as the frequency of exposure to a word increases (Kutas & Federmeier, 2011). However, it is important to note that the effect of cumulative frequency can vary depending on the type of language being processed, with concrete words typically showing a larger effect compared to abstract words. The current study will also investigate the impact of frequency on linguistic processing, while simultaneously controlling for age of acquisition, allowing us to further understand the potential confounding effect where frequency effects could be attributed to AOA.

Whilst the relationship between AOA, concreteness and frequency is complex, a number of hypotheses are formed. First, based on Barber et al. (2013) finding a concreteness effect even after controlling for AOA, such an effect on the N400 component is anticipated. Second, given the notion that early AOA words tend to have more robust semantic representations than late AOA words, it is hypothesised that the impact of concreteness on the N400 may be greater in early AOA words compared to late AOA words. Lastly, assuming that disparities in cumulative frequency are similar to differences in overall frequency, it is predicted that a comparable pattern with the results observed in Dufau et al. (2015) will be found.

Method

Participants

The present study involved 28 participants, ranging in age from 18 to 64 years old (M = 27.79, SD = 12.25). This was a convenience sample of individuals known to the experimenters or attending The University of Adelaide. Participation was voluntary, in exchange for compensation ($100 gift card) and informed consent was obtained prior to participation. Using the Edinburgh Handedness Inventory (short form), participants were categorised as ambidextrous (n = 2), lefthanded (*n* = 2) or right-handed (*n* = 24). All participants were screened to be native English speakers with no reported reading disorders.

Ethics

The study received ethics approval from the Internal Psychology Committee at The University of Adelaide. This approval is granted in accordance with the National Statement on Ethical Conduct in Human Research Guidelines. The experiment was performed within these guidelines, including the obtaining of informed consent from all participants before the experiment was conducted.

Materials

The study used a set of 240 words, categorised into four groups of 60 words based on a 2 (AOA; Early/Late) by 2 (Concreteness; Abstract/Concrete) design. Each group was balanced on letter length, spelling-sound consistency (where the syllable with the lowest consistency was used; see Jared, 2002), orthographic neighbourhood (Andrews, 1989), and concreteness. Reaction times (RTs) were extracted from the English Lexicon project (Balota et al., 2007). The results are summarised in Table 1. Prior to the main task, 10 words and two nonwords were used as fillers. An additional set of 137 and 62 nonwords were also used, although these words were not examined further.

For the purpose of a frequency manipulation, the top 15 most frequent and least frequent words were selected from each of the 4 ANOVA cells, resulting in 60 words for both low and high frequency conditions. As can be seen in Table 2, despite not deliberately trying to balance the words on different conditions, they were well balanced (all p values > .1), apart from RTs, where a difference was expected ($p < .001$). As anticipated, the low frequency words exhibited slower response times compared to their high frequency counterparts in both the naming and lexical decision task (LDT).

Table 1

Reaction Times and Standard Deviation per Age of Acquisition condition

	Reaction Times				Standard Deviation			
	Early AOA		Late AOA		Early AOA		Late AOA	
	Abs	Conc	Abs	Conc	Abs	Conc	Abs	Conc
AOA	5.25	4.92	11.24	11.35	0.61	0.76	1.20	1.11
Concreteness	2.09	4.50	2.10	4.42	0.27	0.32	0.37	0.29
Letters	5.73	5.70	5.85	5.78	1.49	1.51	1.30	1.58
Consistency	0.75	0.77	0.68	0.74	0.20	0.20	0.22	0.20
Log Freq	8.85	8.82	8.67	8.76	1.39	1.40	1.39	1.42
Orth N	4.15	4.95	2.22	3.17	5.47	6.29	4.09	4.84
LDT RT	645	626	687	693	58.54	54.32	66.56	93.09
Naming RT	617	609	657	665	46.03	44.25	57.07	57.89

AOA = age of acquisition, Concreteness = ratings taken from Brysbaert et al., 2014, Letters = letter length, Consistency = how difficult the spelling-sound mapping is, Log Freq = log word frequency, Orth N = orthographic neighbourhood, LDT RT = lexical decision task reaction times taken from Balota, 2007, Naming RT = naming (reading aloud) reaction times taken from Balota, 2007.

Table 2

Reaction Times and Standard Deviation per Frequency condition

	Reaction Times		Standard Deviations	
	Low Freq	High Freq	Low Freq	High Freq
AOA	8.22	8.15	3.19	3.46
Concreteness	3.31	3.28	1.22	1.25
Letters	6.05	5.60	1.44	1.42
Consistency	0.76	0.68	0.18	0.23
Log Freq	6.96	10.24	1.14	0.55
Orth N	2.68	4.03	3.80	5.52
LDT RT	704.64	631.67	91.27	53.77
Naming RT	656.46	625.89	52.36	52.67

AOA = age of acquisition, Concreteness = ratings taken from Brysbaert et al., 2014, Letters = letter length, Consistency = how difficult the spelling-sound mapping is, Log Freq = log word frequency, Orth N = orthographic neighbourhood, LDT RT = lexical decision task reaction times taken from Balota, 2007, Naming RT = naming (reading aloud) reaction times taken from Balota, 2007.

Procedure and Task Description

Participants were comfortably positioned in a brightly lit room, facing a computer screen. The requirements of the task were outlined before the participants completed an informed consent form, which included simple demographic and screening information. The electrode cap was applied and specific instructions for the task were given, notably that if they saw a word, they did not need to respond, but if they saw a nonword, they needed to press a button on a computer keyboard to proceed. Participants were asked to remain as relaxed as possible to reduce movement-related EEG artefacts.

Stimuli was presented in a random order by Matlab v13.0a using the Psychophysics toolbox. The stimuli presentation occurred with each word appearing for 250ms, after which there was a 450ms blank screen. When a nonword appeared, it remained on the screen until a response was recorded. Every 80 trials, a rest screen prompted participants to take a short break and press Esc when they were ready for trials to resume.

EEG Recording and Pre-processing

The EEG signals were captured using a 64Ag/AgCl electrode cap in adherence to the international 10/10 system, with a sampling rate of 1000-Hz. The data were obtained using a Brain Products Brain Amp RT amplifier. The signal was recorded using the Brain Amps software. AFz functioned as the ground electrode, whilst the data was referenced online to FCz. Each electrode site underwent abrasion before use to keep impedances below 10KOhms except for the Iz, T9, and T10 electrodes which were a-priori intended to discard after initial testing showed that T9 and T10 tended to show a poor signal with many participants. The EEG data was collected in a well-lit lab room in The University of Adelaide Health and Medical Science building.

Offline data pre-processing was carried out using Fieldtrip (Oostenveld et al., 2011) with Matlab. Initially, the electrodes Iz, TP9 and TP10 were excluded for each participant. Subsequently, the data underwent bandpass filtering within the 0.1 to 35Hz range. A visual inspection was conducted to identify and address any bad channels, which were reconstructed using data from neighbouring electrodes. Obvious artefacts were removed, and the data were re-referenced to the mastoids.

To decompose the data, independent component analysis (ICA) was applied, using the runica algorithm. Visual examination of the components identified through this analysis was then conducted, and those resembling artefacts related to eye movements, eye blinks, heart beats, impedance, or other factors related to movement were removed. Subsequently, target trials were extracted from -.3 to 1 second, and the average of both mastoids was used to re-reference the data. Finally, using data from -200 to 0 milliseconds before the appearance of the target words, a baseline was established.

Using the visual artefact toolkit, trials were excluded from the dataset applying the following parameters: range (300), kurtosis (20), max *z* value (12), and variance (20). Based on a 4.5SD criterion, further outliers were identified and removed for all of these measures. This caused the removal of 8.09%, 10.99%, 9.75%, and 9.26% in the AOA*Concreteness condition. A further 9.26% and 9.32% of words were removed from the frequency condition. Following this, the individual trials was averaged across the four groups for further analyses.

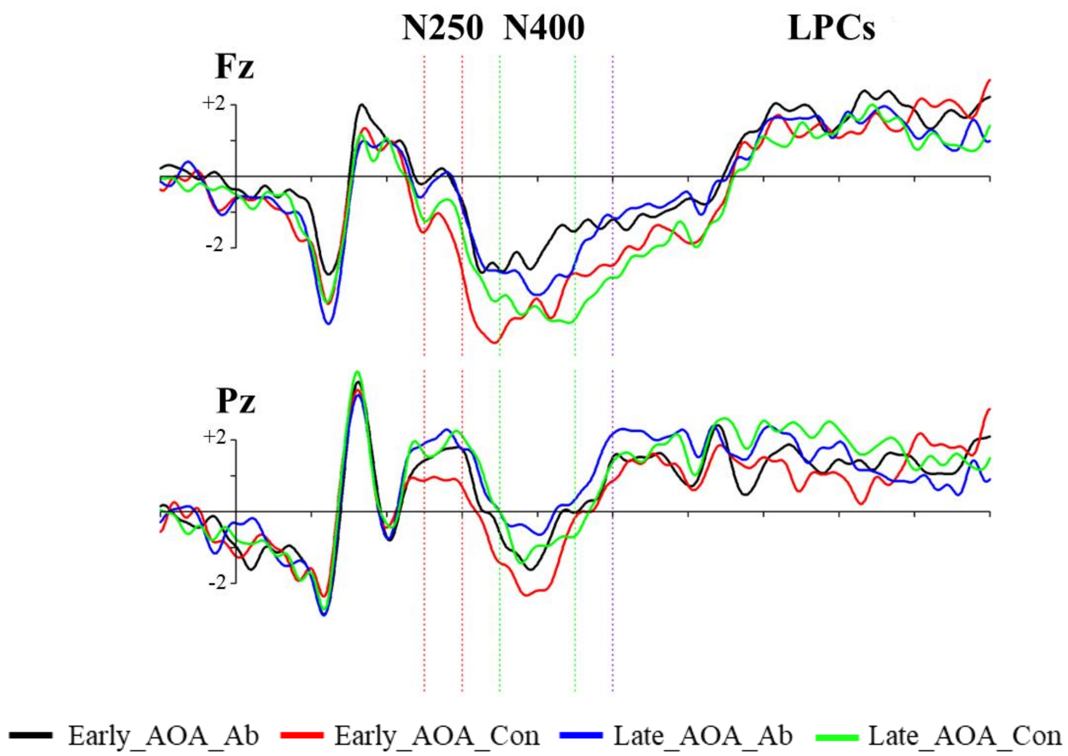
Results

After collection, initial examination of the data showed that one participant's data was unusable, and so they were excluded from further analyses. To assess the hypotheses, ANOVAs were performed on time windows that were either apriori defined based on previous literature (N250, LPCs), or based on finding the highest (P1)/lowest (N1, N400) average point within the ERPs in a given band (N1: 80-120ms, P1:~100ms, N400: 300-450ms) and then creating a 50ms or 100ms (N400) window around it. Data was analysed using the clustering method, and each electrode was analysed to create topographical maps that highlight the electrodes involved in each condition. The clustering method is a non-parametric data driven approach which aims to discover inherent cluster structure in the data.

To get an overall idea of the pattern of data, the grand-averages ERPs were divided into 50ms blocks to look at the significance of each block (see Appendix A). Whilst early effects have been reported for frequency and semantics on early components (Dufau et al., 2015), initial inspection of the 50ms blocks showed no significance in any of them, and therefore data examination started where effects have already been established (i.e. 250ms). Unlike the N400 where the window was found automatically, the N250s and LPCs were chosen by hand since finding an automatic mark cannot be done. The two main effects and the interaction were run in each of these windows. If an interaction was significant, the 4 possible post-hoc comparisons were then tested. The ERPs for each condition is shown in Figure 1.

Figure 1

Grand average ERP waveforms of each variable of interest for two representative electrode sites.

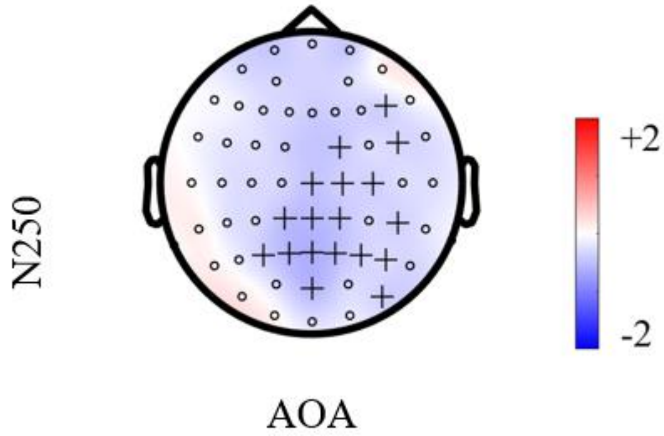


N250

These analyses showed a significant main effect of AOA (p = .033) in the N250 window, with early AOA words eliciting a more positive response than late AOA words. As can be seen from Figure 2, this effect was largely in a centro-posterior region.

Figure 2

Topographic map of EEG activity during the N250 window for the AOA condition (early minus late AOA).



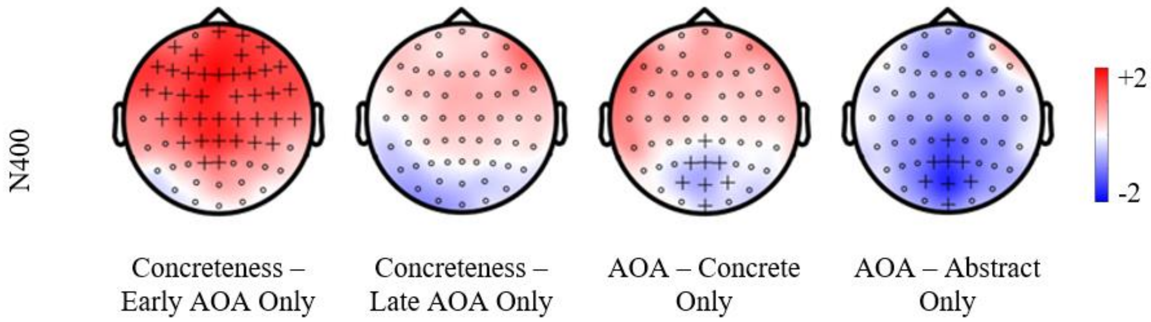
Note: the '+' symbol means the electrode was significant.

N400

This was a main effect of AOA (p = .020), a main effect of concreteness (p = .0042), and a significant interaction between AOA and concreteness (p = .043). To further examine the results, post-hoc comparisons were performed using the Holm-Bonferroni correction. The results showed that there was a significant effect of concreteness with early AOA words (p = .000069) which occurred in fronto-central electrodes, but no significant effect with late AOA words (p = .24). There were notable yet less robust effects of AOA on semantic processing for abstract words (p = .021) and concrete words (p = .013) when examined separately. The effect was strongest in posterior electrodes in both of those groups, as seen in Figure 3.

Figure 3

Topographic maps of EEG activity during the N400 window for interactions between Concreteness and Age of Acquisition conditions.

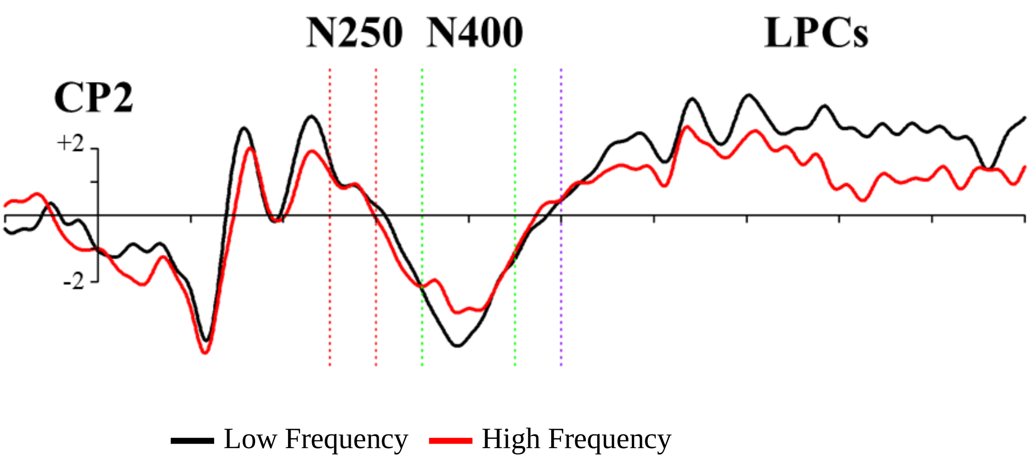


Note: the '+' symbol means the electrode was significant.

In terms of frequency effects, there were no significant effects found. However, the pattern of results was similar to previous research (Dufau et al., 2015), with low frequency words causing a more negative going ERP apart from around the N400, as seen in Figure 4.

Figure 4

Grand average waveforms of low and high frequency variables from a representative electrode site.



Discussion

Numerous studies have explored varying factors that influence semantic processing, such as AOA, concreteness, and frequency. It has been consistently demonstrated that these elements are vital in our ability to process language; however, these effects are often confounded. The present study aimed to further investigate this relationship by examining the effects of age of acquisition as evidenced by ERPs and topography.

The findings of the present study highlight the importance of age of acquisition in semantic processing, a factor which was typically not controlled for in the previous literature. The effect of AOA was observed through semantic tasks and had significant impact on its subsequent semantic processing. Notably, early AOA words yielded a main effect in the N250 window displaying a more positive response compared to late AOA words, which is consistent with Barber et al. (2013). Interestingly, whilst the standard N250 response is typically lateralised, it was not in the present study, where it was more centrally located. This suggests it may represent early semantic processing (Kutas & Federmeier, 2011) rather than the processing of orthographic form (Dufau et al., 2015).

Hypothesis 1: there will be a concreteness effect on N400 even after controlling for AOA.

The first hypothesis expected the effect of concreteness on the N400 occur even after controlling for AOA. The results support this hypothesis, with a significant N400 effect similar to previous research (Holcomb et al., 1999; Kutas & Federmeier, 2011). This result is also evident in the amplitude of ERPs for each condition, with both concrete conditions having more negative N400 responses. The amplified N400 component for concrete words is attributed to a stronger activation of the semantic network (Kutas & Federmeier, 2011), supporting the context-availability model.

These findings suggest that the concreteness effect is not solely determined by age of acquisition, and thus that each of these factors has at least some independent impact on neural processing. Given that these effects of concreteness were largely apparent in the centro-posterior electrodes, the results are consistent with previous research on the N400 (Holcomb et al., 1999; Kutas & Federmeier, 2011).

Hypothesis 2: the impact of concreteness on the N400 will be greater in early AOA compared to late AOA words.

The second hypothesis posited that the effect of concreteness would be greater on early AOA words compared to late AOA words within the N400 window, and this was supported by the results. Notably, early AOA words and concreteness caused a significant interaction, with significant results found in fronto-central electrodes with early AOA words, and no significant results found with late AOA words. Similar results have been found by Gilhooly and Logie (1980). A strong negative correlation between concreteness and age of acquisition in a reaction time task was discovered, suggesting that early AOA words, which tend to be more concrete, are processed more quickly than late AOA words, which tend to be more abstract. This finding supports the idea that concrete and abstract words are processed differently, with concrete words having a stronger representation in the mental lexicon and thus are accessed more rapidly.

These findings show that concreteness affects language processing differently and is dependent on the AOA of a word. The significant interaction between concreteness and AOA suggests that different cognitive processes are involved in processing concrete and abstract words, at least for early AOA words. This supports theories that propose different representations for concrete and abstract words (Gilhooly & Logie, 1980). In research conducted by Kousta et al. (2011), it is concluded that there are distinct ways in which abstract and concrete words are learned, but the role of AOA in the process was not examined. The present study builds upon those findings by investigating the role of AOA on concrete and abstract words. It was discovered that the distinction between abstract and concrete words holds true for early AOA words; however, this distinction was not observed for late AOA words.

Hypothesis 3: frequency LPCs will have a similar pattern to Dufau et al. (2015).

Lastly, it was hypothesised that word frequency would differ in the data, even after controlling for AOA, and that the pattern would be similar to Dufau et al. (2015). The results showed a similar pattern to those of Dufau et al. (2015); however, no significant results were found in the present study.

The observed null effect of frequency can be attributed to several factors. First, frequency effects are generally weak in comparison to other factors that influence language processing. Unlike other studies which typically chose words of different frequencies, the present study instead organised the stimuli according to their frequency. The number of stimuli was thus limited, and consequently, whilst the frequency manipulation is strong, it may not have been as strong as other studies. Therefore, the limited scope of the frequency manipulation may have contributed to the absence of significant frequency effects.

The present study additionally addresses the limitations of previous research by controlling for age of acquisition. Since AOA and frequency are negatively correlated (i.e., words acquired earlier in life tend to be more frequent), failure to control for AOA could have led to confounded stimuli in previous studies. As a result, those studies may have been measuring both frequency effects and AOA effects, which may have conflated the observed differences. Specifically, higher frequency words would have benefitted from the influence of frequency and AOA, increasing the chance of finding differences, but also making it difficult to determine whether the observed differences were due to one, or both, factors. By matching AOA across conditions, the potential impact of frequency effects was minimised, providing clearer results for the role of AOA in semantic processing.

The absence of a significant interaction between frequency and AOA suggests that there is no effect of frequency on the N400 waveform pattern for high versus low frequency words. This suggests that the neural mechanisms underlying the processing of high and low frequency words are not modulated by AOA in a way that interacts with frequency (Kittredge et al., 2008). This finding supports the N400 effects linked to AOA, rather than simply being attributed to disparities in cumulative frequency.

There were also significant findings outside of those initially hypothesised. The findings indicate that there is a significant difference in the AOA effect between concrete and abstract words. However, it is important to note the difference in time-course processing between the conditions. For concrete words, the AOA effect was found to be strongest between 250-400ms, while for abstract words, it was found to be strongest between 400-500ms. This suggests that there is a lag in the AOA effect for abstract words compared to concrete words. One possible interpretation of these results is that the semantics of abstract words are activated with a lag compared to concrete words. This could be due to the fact that abstract words rely more heavily on contextual information and associations to understand the meaning, whereas concrete words have more easily accessible features that allow for faster access to their meaning. Previous studies have shown that abstract words tend to have longer naming latencies and higher error rates compared to concrete words, suggesting that they require more time and effort to process (Schwanenflugel & Stowe, 1989).

The distinction between concrete and abstract words becomes less apparent for late AOA words, suggesting that the process of learning and representing these words may differ to early AOA words. Typically, concrete words are learned through direct experiences with the environment, while abstract words are acquired through social interactions and exposure to language, and often possess multiple meanings (Ponari et al., 2018). However, for late AOA words, the difference between concrete and abstract words becomes less distinct. Both types of words are learned and represented through a combination of direct experience and social interaction, leading to increasing similarity in their representations. Consequently, the representations of abstract and concrete words become increasingly similar for late AOA words. Furthermore, the distinction between concrete and abstract words being less obvious for late AOA words may be due to the fact that concrete words are not necessarily learned independently (Danguecan & Buchanan, 2016). Initially, abstract and concrete words are represented differently, but their representations converge for late AOA words.

This research integrates theories of semantic organisation, which propose different ways in which words are represented and accessed in memory. One such theory is the context-availability model (Schwanenflugel & Stowe, 1989), proposing that a word’s significance is established through its connections to other words and ideas. These findings support this concept by demonstrating that the meanings of late AOA words are learned through associations with surrounding words and concepts, rather than through the retrieval of abstract properties of the words themselves. Consequently, the interpretation of late AOA words is not predetermined by their innate characteristics; instead, it is formed interactively by its associations.

There were a number of limitations observed within this study. Namely, one limitation is that it relied on a single task to assess lexical processing, which may not provide a comprehensive picture of the neural mechanisms involved in language processing. This is because the present findings are limited by the fact that different tasks, such as animal categorisation, reading aloud, and lexical decision, all produce somewhat different effects (Bentin et al., 1995). This in-task variability implies that the extent to which semantic processing varies depending on AOA may not be the same due to task-related differences. For example, semantic categorisation tends to amplify semantic effects, and so it would be interesting to investigate whether concreteness effects would still be absent in late AOA words. If the effects were absent, it would provide further evidence against late AOA words being learnt differently. Conversely, if the effects were still evident, it would indicate that AOA modulates word learning, yet there are still disparities in the learning of abstract and concrete words that manifest later in life.

In summary, the present study examined the relationship between age of acquisition and semantic processing. The results demonstrate that the age of acquisition of a word can significantly impact the way in which it is processed. Specifically, early AOA words that are abstract tend to be processed differently to early AOA words that are concrete, while late AOA abstract and concrete words tend to be processed similarly. This suggests that AOA causes fundamental differences in the way words are lexically organised. In addition, there were no significant effects found for word frequency, a very commonly investigated variable. Whilst further investigation is needed, this suggests that it would be important for future studies to take AOA into consideration when examining frequency, as a potentially important confound. Future research could also explore the neural mechanisms underlying these effects by using fMRI to recognise the regions involved in semantic representations. Additionally, whether similar patterns are observed in other languages and the role of AOA in shaping linguistic representations across cultures could be explored.

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Appendix A: *Grand-Averaged ERPs in 50 ms Time-blocks*

(ms)	**0**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**650**	**700**	**750**	**800**	**850**	**900**	**950**
Abstract/ Concreteness	1.000	0.660	0.368	0.277	0.244	0.153	0.021*	0.007*	0.003*	0.009*	0.095	0.263	0.425	0.123	0.416	0.245	1.000	1.000	0.330	0.358
AOA	0.290	0.157	0.461	0.187	0.200	0.032*	0.001*	0.047*	0.028*	0.036*	0.441	0.169	0.216	0.127	0.096	0.193	0.458	1.000	1.000	1.000
Interaction	1.000	0.584	1.000	0.241	1.000	0.146	0.020*	0.032*	0.249	1.000	1.000	0.301	0.263	0.402	0.285	0.368	0.238	0.210	1.000	0.388
AOA ConcOnly	0.634	0.280	1.000	1.000	0.164	0.022*	0.001*	0.017*	0.086	0.353	1.000	0.087	0.152	0.198	0.064	0.091	0.073	0.114	1.000	1.000
AOA AbsOnly	1.000	0.199	1.000	0.026	1.000	0.418	0.628	0.173	0.006*	0.022*	0.576	1.000	0.407	1.000	1.000	1.000	1.000	0.427	1.000	1.000
Abs/Conc EarlyOnly	1.000	1.000	0.607	0.420	0.378	0.081	0.003*	0.001*	0.001*	0.007*	0.129	0.181	0.155	0.287	0.291	0.356	1.000	1.000	1.000	1.000
Abs/Conc LateOnly	0.823	0.280	0.465	0.217	0.251	0.287	0.110	0.178	0.223	0.168	0.215	0.472	0.216	0.162	0.275	0.143	0.316	0.200	0.288	0.171

Note: * = significant result

Appendix B: Research Proposal

Psychology Honours Project 2023 – Research Plan

Student Name:
Student ID: a1742214

Study Information

1. Title: Understanding the effect of age of acquisition on semantic processing and word frequency: an EEG study.

2. Target Journal: The target journal for this research thesis is Scientific Reports.

3. Research Aim/s: This project aims to understand the relationship between semantic processing, frequency, and the age of acquisition (AoA) of words.

4. Research Question/s:
Can we find evidence that age of acquisition accounts for differences in word frequency and semantic processing by analysing EEG data?
If age of acquisition does account for these differences, when in the time-course of processing do they occur?

5. Use of Theory: Theories of word learning, theories of semantic processing, theories of memory consolidation.
The theory used in this project will be mainly inductive with deductive aspects. The theories of semantic processing and frequency will be used to analyse the role of age of acquisition. It has been established that age of acquisition impacts the way people process words, these effects have not yet been separated from semantic processing and frequency effects.
The working hypothesis is that age of acquisition effects will cause a different time-course and spatial distribution to be found when compared to semantic effects, and to frequency effects.
This research is exploratory in nature and based on positivism. It will influence the research as positivism states that something cannot be known for certain if it is not measurable. The aim is to measure the effects of age of acquisition to know the influence it has on word processing.

Design Plan

6. Tradition (optional): The study will examine the data using Event-related-potentials. Analyses may use frequentist methods or potentially Bayesian clustering methods that allow groups to be found across time and space, and then compared.

7. Study Design: This is an experimental study using electroencephalography. This data will allow for analysis of Event Related Potentials.

8. Study Measures (optional): The independent variables are whether a word has an early or late acquisition and whether a word is concrete or abstract. The dependent variable is data extracted from the event-related potentials.

9. Study Materials (optional): The critical stimuli consist of 400 words that are manipulated using a 2 (Concreteness – High/Low) and 2 (AoA – High Low) design. A second comparison will allow frequency (High vs. Low) to be examined.

10. Study Procedure: All participants are given the same tasks where they are asked to read words that will appear on a screen one at a time. In 1 in 8 trials, a nonsense word will appear, and they must press a button to continue the reading task. EEG data will be collected during this process to be later analysed.

Sampling Plan

11. Existing Data/Partial Existing Data/Original Data (choose one)
Original data.

12. Data Collection Procedures
Data will be collected from a mixture of participants recruited from the first-year participant pool, along with friends and associates of the researchers. This will be convenience sampling, as this study only requires for participants to be a native English speaker without any form of reading disorder and does not have any other exclusion criteria.

13. Type of Data Collected:
Electroencephalography.

14. Sample Size: The sample size for this study is 28, as based on current literature within the area of research. 28 participants have been shown to be sufficient to demonstrate any effects clearly.

15. Stopping Rule: When the set sample size of 28 subjects is reached.

Analysis Plan

16. Data Analyses:
The data will be examined using standard methods for EEG data. The Fieldtrip package will be largely used along with Matlab and R. My supervisor coradwill help out with this analysis.

Other

17. Other (Optional):