Investigating the Electrophysical Correlates of Language Processing Regarding Age of Acquisition and Emotion.

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Abstract:

The emotional characteristics of written words is well known to effect how they are processed. It is also well known that how early in life words are learnt (i.e., their age of acquisition – AOA) also effects how they are processed with early AOA words being processed more efficiently than late AOA words. However, the impact of this phenomenon on the processing of written emotional words has not been studied. Using event-related potentials, this effect was investigated on the processing of such words. The results showed a strong and sustained effect of AOA effect from very early in processing (100 ms). Alternatively, there was no effect of early posterior negativity around 250 ms, which has been suggested to be a marker of early attentional capture of emotionally arousing words. The effect AOA produced at this time had a similar topography as early posterior negativity, suggesting that this may have been a potential confound in previous studies. The results also showed that emotional status interacted with AOA on the N400, a well-known marker of semantic processing, where emotional words showed an effect of AOA, but emotionally neutral control words did not. This suggests that the way semantic is learnt in affective words differs depending on their AOA. Further analyses examining the effect of AOA on alpha desynchronization found that late AOA words caused more desynchronization than early AOA words suggesting they are more difficult to process. However, the lack of an interaction with emotional status suggests that emotion causes qualitatively differences in processing, rather than simpler more-or-less processing.

Keywords: Age of Acquisition, Emotion, Language Development, EEG

Declaration:

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Contributor Roles Table:

ROLE	ROLE DESCRIPTION	STUDENT	SUPERVISOR 1
CONCEPTUALIZATION	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 materials, 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 reuse.	**X**	
FORMAL ANALYSIS	Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data.		**X**
VISUALIZATION	Visualization/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**

Chapter 1: Introduction

The extent to which humans react to things in our environment differs depending on the affective characteristics of the stimuli, such as whether they are a threat or promote wellbeing. Early research showed that people can react to threat related objects and events very quickly, and it was argued that this was because of the ecological importance of avoiding harm (Adolphs, 2002). Thus, if something is dangerous (e.g., a knife), they might need to be reacted to faster than something that is not (e.g., a dead animal). It has also been argued that this can occur automatically via bottom-up attentional capture, which could then affect the way stimuli are processed compared to when bottom-up attentional capture had not occurred (West et al., 2009).

More recent research has examined different kinds of affective information, including things where there is not a strong ecological reason for fast reactions, such as affectively positive written words. Interestingly, such words also appear to cause fast attentional capture (Kissler et al., 2009). West et al. (2009) argued that it is not particular types of things that cause fast attentional capture, but rather simpler emotional cues that cause arousal. Thus, it does not initially matter whether something is arousing, but because it has positive emotional affect or negative emotional affect it can still cause quick attentional capture.

1.1: Measuring early attentional capture using Event-related Potentials

Reaction time to objects can be measured via the use of event related potentials (ERP). ERPs are a voltage measurement of neural activity that can be recorded non-invasively from multiple scalp regions through electroencephalography (EEG). Neural generator sites can also be estimated by determining the location of ERP components (Schupp et al., 2006). The localisation of the ERP provides important information regarding their functional significance and result from a specific sensory event, as well as providing valuable information regarding the guidance of selective attention (Schupp et al., 2006).

There are a number of ERP components that come into play when measuring language processing. These can be classified into the relatively early processing of the phonology/orthography of words (EPN, N250; (Holcomb & Grainger, 2006)), the semantic processing of words (N400; (Chwilla et al., 2011; Kutas & Federmeier, 2009)), and more general strategies such as visualising stimuli, typically known as late positive components (LPCs; (Friedman et al., 1975; Zhang et al., 2014)). Alpha desynchronisation can also be used to examine the extent of attentional capture and its kick-on effects (Pfurtscheller & Da Silva, 1999).

1.2: Important ERP Components

N1: The N1 ERP marker is a negative component peaking around 100 ms after stimulus presentation. The N1 seems to be involved in visual processing of spatial information and is assumed to reflect sensory processing of incoming information (Wascher et al., 2009).

EPN: An important ERP marker associated with the early attentional capture of emotional stimuli caused by arousal is known as early posterior negativity (EPN) (Jaspers-Fayer et al., 2012; Peyk et al., 2009). EPN peaks between 200 and 300 ms after the presentation of a stimulus (Kissler et al., 2009). It appears as a negative-going component over temporo-occipital sensor sites and a corresponding polarity reversal over fronto-central regions (Schupp et al., 2006). The actual type of emotional information does not appear to effect EPN much which is consistent with the hypothesis that it is a measure of arousal and not indicative of the type of emotional information (Jaspers-Fayer et al., 2012).

Age of Acquisition and affective words

The EPN marker is not limited to pictures and faces but has also been observed in written words. This has been illustrated in simple reading tasks where participants are not explicitly asked to process the meaning of the words (Zhang et al., 2014). This suggests that attentional capture can come from stimuli with no evolutionary basis for it, therefore, the attentional capture is likely to be caused by the semantic processing of the words or the association of the word with affective responses.

N250: The N250 has been argued to occur at a very similar or briefly later timeframe than EPN (Holcomb & Grainger, 2006). The N250 is a negative-going component which peaks nearly 250 ms after the presentation of a stimulus (Holcomb & Grainger, 2006). It has a broad scalp distribution with the largest effects occurring over more frontal sites (Holcomb & Grainger, 2006). The N250 is thought to be sensitive to a system involved in processing relative positions of a word's constituent letters as ordered letter combinations are formed, used to generate a sublexical phonological code and access the whole-word orthographic representations (Holcomb & Grainger, 2006).

N400: The N400 is elicited by relatively complex semantic processing (c.f., simple access of semantics) (Kutas & Federmeier, 2009). It occurs around 400 ms after stimulus presentation and causes a more negative going ERP (Kutas & Federmeier, 2009). The N400 effect is a single-phase negativity between 200 and 600 ms and is largest over centro-parietal sites, typically with a slight right hemisphere bias (Kutas & Federmeier, 2011). Whilst the classic work on the N400 was done examining semantic anomalies, it has also been found with the processing of semantic features in concrete vs. abstract words, semantic priming, semantic and recognition memory, object, face, action and gesture processing, and mathematical cognition (Kutas & Federmeier, 2011).

LPCs: Late positive components are markers of more complex and later processing that are potentially open to strategic biases. LPCs increase at centro-parietal electrode sites when viewing emotional stimuli (e.g., words, faces, words) (Zhang et al., 2014). These can also differ depending on the task. For example, in language tasks, this can include the visualisation of words and the reinterpretation of the meaning (Friedman et al., 1975). LPCs report late effects and reflects a more elaborate processing stage likely associated with attentional capture, evaluation, and memory encoding (Zhang et al., 2014).

Alpha Desynchronisation: This metric summarises the strength of oscillatory activity in the 7-13 Hz band from EEG data (Pfurtscheller & Da Silva, 1999). This is a measure of the intensity of alpha-waves at any given time. Pfurtschuller & Da Silva (1999) argued an increase of task complexity or attention corresponds to an increased magnitude of alpha desynchronisation (i.e., less alpha waves being detected), representing an increase in the processing of the stimuli. There are two distinct patterns of alpha desynchronisation; lower alpha desynchronisation (7-10 Hz) is related to processing demands, and upper (mu) alpha desynchronisation (10-12Hz) is related to the semantic processing (Pfurtscheller & Da Silva, 1999).

In this study, if stimuli of emotional importance are the subject of attentional capture and processed more, a greater amount of desynchronisation would be expected in lower alpha. Similarly, if attentional capture causes more semantic processing, upper alpha desynchronisation would be expected to increase. This distinction is somewhat speculative, thus, alpha desynchronisation is inspected as a whole in this study to gain a comprehensive view of changes in the alpha band across the entire range.

1.3: Does Age of Acquisition affect the processing of emotion?

An important aspect of emotional words that has not been examined in the context of language development and processing is age of acquisition (AOA). Examining AOA is pertinent because the temporality of emotional words differs significantly, with the proportion of emotional words in the early lexicon being much higher than the late lexicon (Cortese et al., 2020). For example, *love* is a word typically acquired at an earlier age as compared to *despair* which is typically acquired much later. It has also been argued that the age at which words are learnt is important for understanding how their semantic and orthographic properties might be represented (Hernandez & Li, 2007). Research has found that emotions play a central role in the development of abstract word categories, as abstract words (e.g. *justice*) tend to be more emotionally charged than concrete words (e.g. *courtroom*) (Kousta et al., 2011). A study by Ponari et al. (2018) found that positive and negative abstract words are acquired earlier than neutral words, signifying the crucial role of emotion in the acquisition of abstract words. Emotion words acquired at an early stage benefit from processing advantage over late, with early AOA emotion words being recognised more efficiently than late AOA emotion words, reflecting significant influence of learning sequences in language processing (Wu et al., 2023). Over the years, several theories describing AOA have been introduced.

1.4: Theories of AOA

One theory of AOA is the *cumulative frequency hypothesis,* that is, how often a word has been encountered over a discrete time period. Previous research has determined that AOA effects are so closely related to frequency that they cannot be behaviourally distinguished (Adorni et al., 2013). During standard psycholinguistic experiments, researchers typically examine word frequency based on counts derived at a particular time. However, this may incorrectly estimate the frequency at which someone has been exposed to a word – that is cumulative frequency of a word (Zevin & Seidenberg, 2004). Given this, if high frequency words tend to be processed more easily and their affective characteristics habituate due to overuse, as occurs with swear words (c.f., 'motherfucker' vs. 'unclefucker'), then one might expect a reduced emotional effect with early compared to late AOA words (Kuperman et al., 2012). Research by Adorni et al. (2013) concluded that AOA has a much more distributed effect than word frequency and affects multiple levels of word recognition processing.

A second theory is the *arbitrary mapping hypothesis,* the theory that word learning processes may differ early in life (Kuperman et al., 2012). The arbitrary mapping hypothesis assumes that AOA effects reflect the arbitrary nature of the mapping between input and output representations formed during the development of the lexical network (Chen et al., 2007). AOA effects appear to reflect increased rigidity and reduced plasticity of the networks as a result of the learning process, thus, late learned words are incorporated into the sematic representations already existing in earlier learned words (Hernandez & Li, 2007; Xue et al., 2017). Speed and efficiency in semantic activation may thus in part be determined by order of acquisition and hence early learned concepts are more accessible compared to late learned concepts (Xue et al., 2017).

A third theory is the *abstractness effect* established by Kousta et al. (2011). They suggest that abstract words have a processing advantage over concrete words because of their affective associations, although concrete words were not examined in this study (Kousta et al., 2011). The authors further suggest that new concepts with a late AOA are formed by making associations with already established concepts and earlier acquired words tend to be learnt with reference to the simple semantic features (Cortese et al., 2020). If this is the case, then one might expect early AOA words to access their meaning earlier and potentially with less competition from other words. This may cause early AOA words to elicit an earlier and potentially stronger EPN than late AOA words. In terms of the N400, the prediction is less clear. One might predict that late AOA words would cause a more negative going N400 due to more semantic associations being processed. Alternatively, if the semantics of early AOA words is processed more because it is simpler to retrieve, then they may produce a more negative N400.

Chapter 2: Study Hypotheses

In this study, EEG was used to investigate whether AOA has an effect on the processing of emotional language. The effect of AOA and arousal (using emotion words) were manipulated, and their effect was measured using ERP amplitudes and alpha desynchronisation. The study aims to fill the gap in the literature regarding the role of AOA in processing of written words with emotional characteristics.

2.1: Hypothesis 1

Both emotion and neutral words will show an AOA effect in the ERP data. This is consistent with all three hypotheses. In this case, having a high cumulative frequency would cause processing differences to have a low cumulative frequency. Further, differences in arbitrary mappings should affect semantic processing, and differences between associations formed should also elicit differences in ERPs.

2.2: Hypothesis 2

Early AOA words will produce less alpha desynchronisation compared to late AOA words because they require less processing. This is consistent with a cumulative frequency explanation which predicts that high frequency words should be easier to process than low frequency words. It is also consistent with the Abstractness Effect; whereby early AOA words should have simpler and fewer word associations than late AOA words. In terms of ERPs, words with larger numbers of associations should cause a more negative N400 effect than words with fewer (see Laszlo & Federmeier (2011)).

2.3: Hypothesis 3

Emotion words will cause a divergence in ERPs at the N400 due to semantic and emotional associations with other words. Kousta et al.'s Abstractness Effect predicts that late AOA words will have a larger effect on the N400 compared to early AOA words due to more semantic and less emotional associations with other words.

Chapter 3: Methods

3.1: Participants

The participants were 28 healthy individuals (11 male, 17 female) aged from 18 to 64 years (average = 28, SD = 12.24). These were a convenience sample consisting of individuals from the University of Adelaide or known to the experimenter and were recruited via word of mouth, the University of Adelaide's first year psychology research participation program tool (SONA), and an announcement shared by the School of Psychology. Participants were native English speakers and did not have any form of reading disorder. Participation information was shared and eligibility criteria were initially assessed via email prior to lab attendance. Ethics for this study was approved by the University of Adelaide Ethics Committee. This ethics approval satisfies the National Statement on Ethical Conduct in Human Research Guidelines written by the National Health and Medical Research Council of Australia, and our experiment was performed within these guidelines. Informed consent was obtained from all participants prior to their participants (see Appendix A for complete information, consent, and the SONA advertisement).

3.2: Stimulus Material

Two hundred words which were broken down into 4 groups of 50 words based on a 2 AOA (Early/Late) by 2 Arousal (Low/High) design. The words with high arousal were broken down further into positive and negative words. However, due to the limited number of stimuli available, these were not intended *a priori* to be used in a 3-way ANOVA with the EEG data. The words were balanced across groups on letter length, spelling-sound consistency (where syllable with the least consistency was used), orthographic neighbourhood, and concreteness. All statistics were taken from the English Lexicon Project (Balota et al., 2007) apart from spelling-sound consistency (Perry et al., 2010), valence (Warriner et al., 2013), arousal (Warriner et al., 2013), and concreteness (Brysbaert, et al., 2014). These are summarised in Table 1 and measured as a function of stimuli valence in Table 2. A further 8 words and 2 nonwords were used as fillers before the main experiment, and the main stimuli were randomly interspersed between a further 178 words and 62 nonwords.

Table 1:

Reaction Times per Age of Acquisition Condition (means and SDs)

	Mean				**Standard Deviation**			
	Early		Late		Early		Late	
	Emotion	Control	Emotion	Control	Emotion	Control	Emotion	Control
AOA	5.59	5.29	11.25	11.54	0.90	0.91	1.12	0.89
Letters	5.94	5.70	6.06	5.90	1.43	1.18	1.38	1.30
Consistency	0.74	0.72	0.62	0.69	0.23	0.26	0.26	0.22
Log Freq	8.29	8.74	7.93	8.55	1.23	1.46	0.94	1.59
Orth N	3.78	3.78	2.14	1.96	4.25	5.02	3.71	3.46
LDT RT	641	634	709	699	56.50	54.82	62.84	94.98
Naming RT	628	632	659	662	57.68	58.90	57.96	59.30
Valence	4.82	4.80	4.64	4.87	2.26	0.68	1.92	0.41
Arousal	5.72	3.98	5.81	3.84	0.61	0.69	0.38	0.58
Concreteness	3.16	3.18	2.89	2.99	0.95	0.83	0.82	0.96

AOA = age of acquisition, Letters = letter length, Consistency = difficulty of spelling sound mapping (Perry et al., 2010), Log Frequency = log word frequency, Orth N = Orthographic neighbourhood, LDT RT = Lexical decision task, Naming RT = Naming (reading aloud) reaction time, Valence = Valence of a word between 1 (negative) and 7 (positive) (Warriner et al., 2013), Arousal = how arousing a word is (Warriner et al., 2013), Concreteness (Brysbaert et al., 2014)

Table 2:

Reaction Times per Age of Acquisition Condition as a Function of Stimuli Valence (means and SDs)

	Mean				Standard Deviation			
	Early		Late		Early		Late	
	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos
AOA	5.40	5.79	11.28	11.22	0.87	0.90	1.22	1.03
Letters	5.96	5.92	5.84	6.28	1.49	1.41	1.11	1.59
Consistency	0.73	0.74	0.58	0.66	0.22	0.25	0.27	0.25
Log Freq	8.39	8.19	8.11	7.75	0.97	1.45	1.01	0.84
Orth N	3.80	3.76	2.20	2.08	4.54	4.03	3.97	3.52
LDT RT	641	641	713	704	58.71	55.41	63.31	63.31
Naming RT	630	626	659	659	62.36	53.80	59.99	57.09
Valence	2.65	6.99	2.83	6.46	0.53	0.62	0.43	0.71
Arousal	5.67	5.77	5.93	5.69	0.66	0.56	0.32	0.39
Concreteness	3.39	2.93	3.13	2.65	0.87	0.98	0.83	0.75

AOA = age of acquisition, Letters = letter length, Consistency = difficulty of spelling sound mapping (Perry et al., 2010), Log Frequency = log word frequency, Orth N = Orthographic neighbourhood, LDT RT = Lexical decision task, Naming RT = Naming (reading aloud) reaction time, Valence = Valence of a word between 1 (negative) and 7 (positive) (Warriner et al., 2013), Arousal = how arousing a word is (Warriner et al., 2013), Concreteness (Brysbaert et al., 2014)

3.3: Procedure and task description

Participants were seated comfortably in front of a computer screen in a well-lit room where they signed an informed consent form, as well as simple demographic and screening information. The task was explained to the participants, after which the electrode cap was applied. Before the task started, the instructions were completed, including asking them to remain relaxed to reduce muscle and eye movement EEG artefacts. The instructions also included being told that the task was lexical decision, and that they were only to respond when a nonword appeared, which was to be done by pressing the left arrow key on a keyboard.

Matlab v13.0a using the Psychophysics toolbox was used to present the stimuli, which were presented in a random order. The stimuli presentation occurred with each word appearing for 500 ms, after which there was a 1500 ms blank screen. When a nonword appeared, it remained on the screen until participants responded. Every 80 trials, participants got a screen appear telling participants to have a rest. When they pressed the “ESC” button, the trials were restarted.

3.4: EEG recording and Pre-Processing

The EEG was recorded using a 64Ag/AgCl electrode cap using the international 10/10 system, sampling at 1000 Hz. The data was obtained using a Brain Products Brain Amp RT amplifier and the signal was recorded using the BrainLab software. The data was referenced online to FCz whilst AFz acted as the ground. All electrode sites were abraded to keep impedances below 10 KOhms apart from Iz, T9, and T10 electrodes which were *a priori* intended to discard. The data was collected in the Clinical Research Facility lab room at the Adelaide University Health and Medical Science building.

Pre-processing of the data was done offline using Fieldtrip version 2021129 with MATLAB (R2022a). Initially, data was bandpass filtered between 0.1 and 35 Hz, and electrode TP9, TP10, and Iz were removed. The data was then visually inspected for bad channels, which were reconstructed based on neighbouring channels, and obvious artefacts were removed. The data was re-referenced to the mastoids and independent component analysis (ICA) was used to decompose the data (runica algorithm). Components identified by this analysis were visually checked, and any that resembled eye blinks, eye movements, heart beats, impedance, or other movement related artefacts were removed. Target trials were then extracted from -300 to 1000 ms and the data was re-referenced to an average reference. The data was then redefined using a baseline from -200 to 0 ms before the target words. Bad trials were automatically removed using FieldTrip’s toolbox. Trials were initially removed using the visual artefact toolkit if the values went over the following parameters: Range: 300; kurtosis: 20; max *z* value: 12, variance: 20. This caused the removal of 9.58%, 8.64%, 9.58%, and 8.80% in the late AOA affective, early AOA affective, late control, and early control conditions, respectively.

3.5: Cluster Analysis

Cluster analysis was used to provide insights into the temporal and spatial patterns of brain activity (Sassenhagen & Draschkow, 2019). Cluster analysis is a non-parametric statistical test that does not depend on the data having a normal distribution within each condition. This analysis compares the observed value to a test that is obtained by creating a distribution from a set number of permutations of the original data (Maris & Oostenveld, 2007). It thus only gives a p-value and no other statistics such as a F-value or degrees of freedom.

Chapter 4: Results

Of the 28 participant datasets, 27 datasets were deemed usable. Initial inspection of the data showed that one participant's data was unusable due to high impedance causing significant noise, so they were excluded from the analyses. All the possible effects and comparisons in time blocks of 50 ms increments was initially inspected to gain a general impression of the results (see Table 3). It was evident from these time blocks that AOA was clearly the strongest effect, with significant effects occurring across most of the time distribution. There were weaker effects of emotion that also occurred late in the time distribution, as well as potential interactions where the AOA effect was greater with emotional compared to non-emotional words.

Next, to examine the data, a 2 arousal (low vs. high) by 2 AOA (early vs. late) ANOVA was used and interactions between them were examined on all time windows. Example electrodes appear in Figure 1.

Table 3:

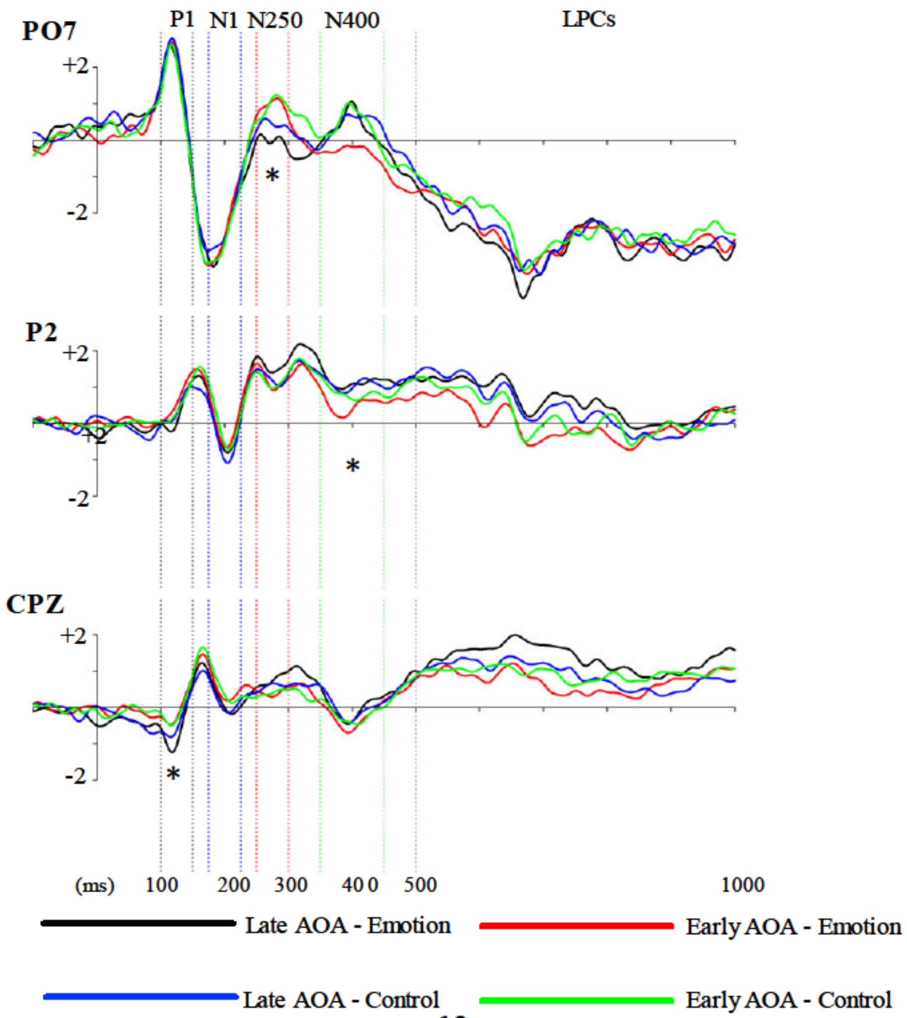
P-values (uncorrected), for the possible effects and comparisons examined in 50ms time blocks

	N1		N2		N250			N400				LPC				
Effect	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
Emotion						.089		.044	.060			.055				
AOA	.012	.016			.012	.046	.026	.002	.020	.078	.005	.012	.000	.001	.007	
Interaction							.012					.042	.058	.008		.010
Emotion E.v.L		.068			.017	.070	.001	.024	.072		.004	.005	.001	.000	.010	.004
Control EvL	.054		.042										.095			
Emotion E.v.C							.003									
Emotion L.v.C						.031					.094	.058	.049			.009

Note: E = early, L = late, C = control

Figure 1:

*Example Electrodes of Grand-Average ERPs. Note: * represents a significant effect (N1, N250) or interaction (N400).*

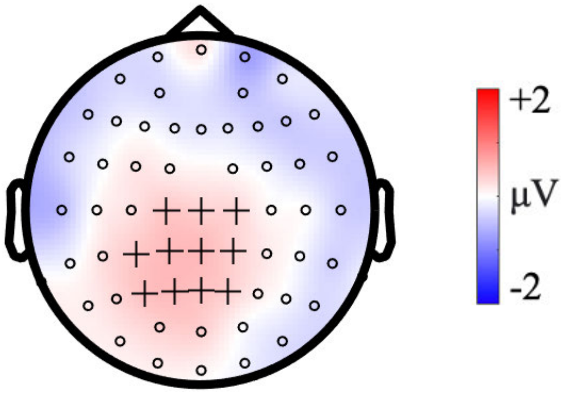


4.1: N1 Window

There was a significant negative going early AOA effect (p = .012) at 100-150 ms with the largest effect occurring in centro-posterior electrodes.

Figure 2:

Topographic map of the effect of AOA at the N1 Window (Early-Late). Significant electrodes are represented with a '+'

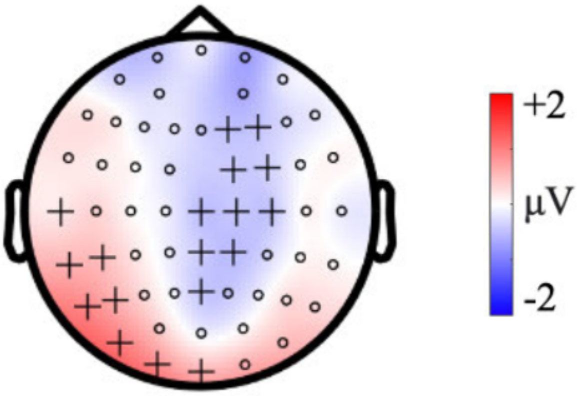


4.2: EPN/N250 Window

Contrary to expectations, there was no significant interaction between AOA and arousal. However, there was a significant AOA (N250) effect (p = .0098) that occurred with a similar topographic distribution as found with EPN, although only electrodes in the left-hemisphere differed significantly.

Figure 3:

Topographic map of AOA effect (Early-Late) in the EPN/N250 window. Note: the central electrodes are only significant late in the time-window.

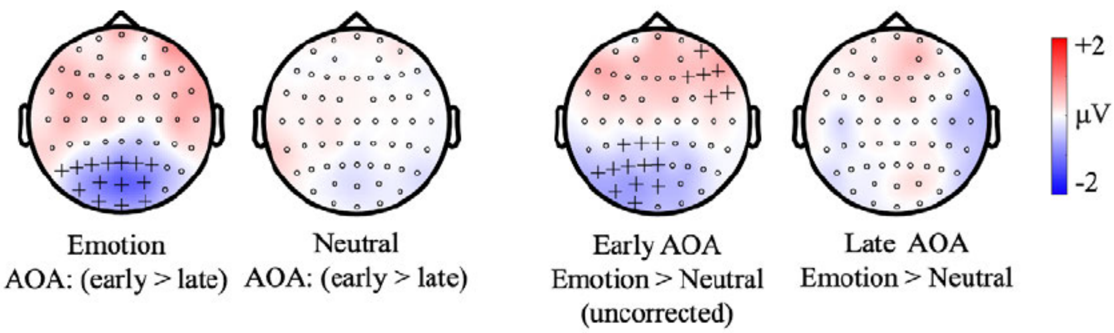


4.3: N400 Window

There was a significant main effect of AOA (p = .0018) with early AOA words more negative going than late AOA words. There was also a significant main effect of emotion (p = .011) where positive words were more negative going than negative and neutral words. Results of post-hoc comparisons (see figure 4) showed that there was a significant effect of AOA in the emotion condition (p = .002) as well as a significant effect of emotion with early AOA words (p = .037), although only using an uncorrected comparison.

Figure 4:

Topographical Maps of the Effect of AOA x Emotion at 400ms (N400) After Stimulus Presentation

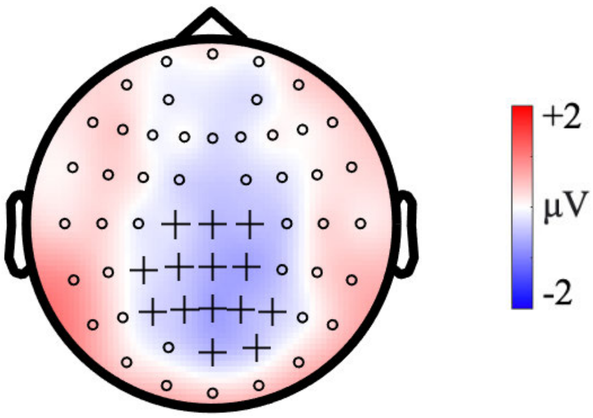


4.4: LPC Window

There was a significant effect of AOA with late AOA words being more negative going than early AOA words (p = .0004).

Figure 5:

Topographical Map of the effect of AOA (Early-Late) in the LPC window. Significant electrodes represented with a "+"



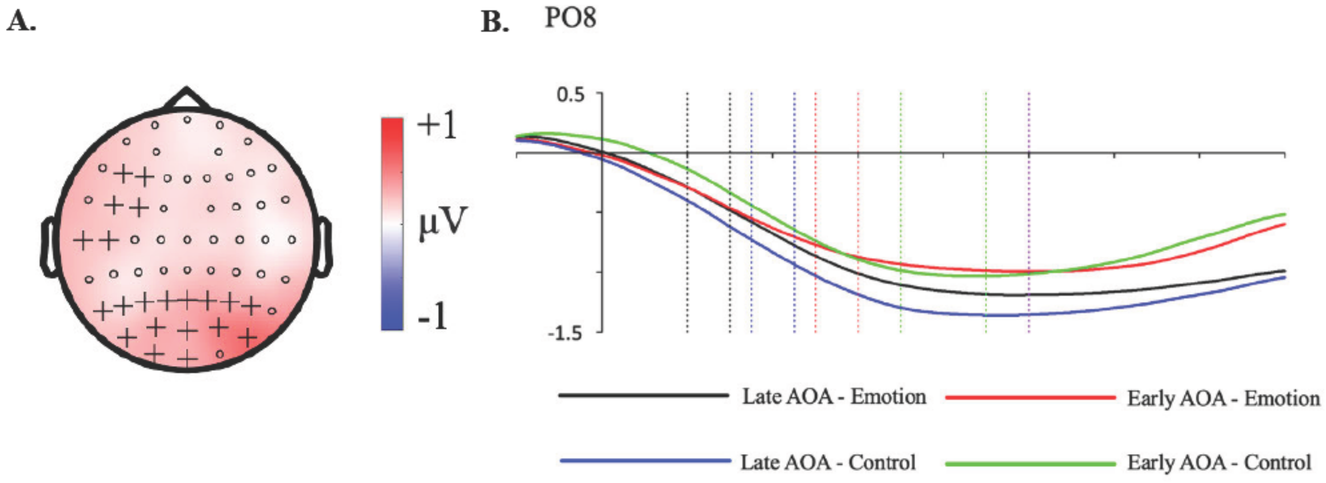
4.5: Alpha desynchronisation

There was a significant negative going alpha desynchronisation in the LPC window (p = .0066) with late AOA words being more negative going than the early AOA words (see figure 6). The effect was strongest in posterior and left-frontal areas.

Figure 6:

Figure A: Topographical map of alpha desynchronisation effect (Late-Early). Note: significant electrodes represented with a "+"

Figure B: Example grand-average electrode of alpha desynchronisation for all groups



Chapter 5: Discussion

5.1: Summary

The primary concern of the present study was to understand the effect of AOA on the processing of emotional language. The focus of this study was the processing of written language, using selected AOA words from the English Lexicon Project (Balota et al., 2007). There is a large body literature examining how emotional language processing is influenced by developmental experience and it has commonly been noted that this aspect of language development is important, though, there is lack of research looking into the effect of AOA on this processing (Adolphs et al., 2002; Chwilla et al., 2011; Zhang et al., 2014).

Our results indicated that there was a significant effect of AOA at three of four of the time windows examined, confirming our first hypothesis that both emotion and neutral words will show an AOA effect in the ERP data. The results were similar to Grainger et al. (2015) who examined word frequency, in that the results produced both early and late effects of AOA.

They suggested that the effect of frequency may be coming from different sources at different times, and this is also likely to be true of our results with respect to AOA. In regard to our second hypothesis, there was more alpha desynchronisation for late AOA words compared to early AOA words, consistent with the cumulative frequency hypothesis and abstractness effect. This supports the proposition that early AOA words have simpler associations than late AOA and are hence easier to process. In regard to our third hypothesis, the results showed that early AOA words with emotional characteristics produced a more negative going N400 than late AOA words. This is contrary to what the abstractness effect (Kousta et al., 2011) predicts, which is the opposite of our results. These results are important as they highlight the need to understand emotional language processing and how it might be influenced by development. We will return to why this may have occurred below.

5.2: Evidence of Cumulative Frequency Hypothesis

The cumulative frequency hypothesis predicts that high frequency words should be easier to process compared to low frequency words due to the accumulated exposure over time. Early AOA words tend to have higher frequency due to higher usage in everyday language. The results from examining alpha desynchronisation support this effect as early AOA words produce less alpha desynchronisation, thus, are processed more efficiently. This finding is consistent with a large amount of literature that has examined the word frequency and AOA effects in behavioural studies, which have shown high frequency and early AOA words are faster to process than low frequency and late AOA words (Adorni et al., 2013; Zevin & Seidenberg, 2004; Zheng & Lu, 2015). Thus, less processing effort should cause less alpha desynchronization, which was replicated in this study.

5.3: Evidence of Arbitrary Mapping Hypothesis

Our results indicated a significant main effect of AOA on the N400 where early AOA words were more negative going than late AOA. This result is consistent with the arbitrary mapping hypothesis which suggests that early AOA words are more accessible than late AOA words due to early AOA words having more semantic interconnectedness (Hernandez & Li, 2007; Xue et al., 2017). It is likely that the AOA effect reflects increased rigidity and reduced plasticity of networks as a result of the learning process, and late learned words are incorporated into semantic representations already existing from earlier learned words (Chen et al., 2007). Furthermore, a study by Hernandez & Li (2007) has suggested that late AOA words elicit activation in brain areas that suggest effortful retrieval, whereas early AOA words tend to elicit more semantic processing. This data is entirely consistent with our results.

5.4: Evidence of Abstractness Effect

Kousta et al. (2011)'s abstractness effect suggests that late AOA words would produce a stronger effect than early AOA words due to more semantic and less emotional associations. Our results indicate that early AOA words with emotional characteristics have more semantic associations compared to late AOA words with emotional characteristics. Alternatively, the abstractness effect is supported by the results from analysing alpha desynchronisation, which confirms that early AOA words have simpler associations, thus, require less processing.

5.5: Efficiency of Processing of Early AOA Words Compared to Late AOA Words

There was a significant main effect of emotion on the N400 where positive words were more negative going than negative and neutral words. The effect does not initially look like an N400 as it is lateralised to more left occipital-parietal areas where normally it is more central. Early AOA words showed a more negative going N400 compared to late AOA words, suggesting that the semantics of early AOA were processed more efficiently than late AOA.

This is contrary to Kousta et al. (2011)'s abstractness effect where late AOA words are expected to produce a stronger N400 than early AOA words. Although, these results are consistent with the findings of Wu et al. (2023) who found that emotion word recognition was influenced by AOA, and that early acquired emotion words were processed more efficiently than late. This provides stronger evidence of the presence of an AOA effect on emotional words, emphasising the importance of considering AOA in research of emotional word processing. These results indicate that early acquired words have denser semantic networks and connections within the lexical network and form the basis for concepts acquired later in life. This was further supported when examining the extent to which these words caused alpha desynchronisation and indicated that early AOA words caused less alpha desynchronisation than late AOA. These results have importance because they suggest that late AOA words have more semantic and less emotional content than early AOA.

5.6: Impact of AOA on emotional words

Contrary to expectations, there was no EPN effect found, which has previously been reported with emotional words as a marker of attentional capture. However, there was a somewhat left lateralised posterior effect produced on the N250. This was similar to the results found by Adorni et al. (2013), who found activation within the left posterior area when testing for AOA. This representation is unlike the representation for frequency, which activates centrally, contradicting the cumulative frequency hypothesis (Adorni et al., 2013). Looking at figure 2, it is evident that there is a bilateral difference in areas typically associated with EPN, although the effect was slightly stronger in the left lateralised region compared to a typical EPN representation. Without controlling for AOA, this effect could be easily mistaken for EPN, potentially a confound in previous emotion studies. This is because AOA and word arousal are moderately correlated, and thus selecting stimuli based on arousal means without controlling for AOA, stimuli with high arousal would also tend to be of early AOA than neutral stimuli.

There is a possibility that there was not EPN detected due to the task demands of the experiment. Specific tasks performed can have an impact of the processing of emotional words (Sanchez et al., 2015). If the task requires the participant to focus on non-emotional aspects of the stimuli, the EPN response may be reduced, and our task did not explicitly direct attention to the emotionality of the words. An MRI study from Yang and Zevin (2014) on the impact of task demands on visual word recognition determined that different task demands on semantic, phonological and orthographical processes can influence the involvement of the relevant regions during visual word recognition. Other studies investigating the effect of task demands in written word tasks found that the EPN was enhanced for emotionally arousing words regardless of whether the word belonged to a target or non-target category (Kissler et al., 2009; Schacht & Sommer, 2009). Thus, the literature here is not consistent, and whether this could be responsible for our results rather than just simple statistical noise is unclear.

In terms of processing after the EPN, the impact of emotion was greater in early AOA than late AOA words as indicated by significant results and the interaction found on the N400 where early AOA words differed significantly, but late AOA words did not. This is interesting because it suggests that the representations in the lexicons of emotional words differs depending on AOA. One possibility as Kousta et al. (2011) suggests is that abstract words tend to be learn with respect to associations with other words and their meanings (‘metaphorical analogy’). However, for late AOA words, it is conceivable that this becomes the standard way that most words are learnt, rather than on their simple semantic characteristics. If this is the case, one might expect a difference between early and late AOA words as was found in this study.

5.7: Outcomes and Implications

Our results inform us on the structure of the mental lexicon and the way it is accessed. It is not a simple system where word form access semantic features directly, but rather, words have different semantic organisations and different ways they are accessed. These results inform our understanding of how emotion related information is being represented in the mental lexicon and how it influences word meaning and usage. Our results indicate that AOA effects semantic processing and determines the speed with which the semantic representations of concepts can be activated. It also appears to be involved with the way the lexical system is organized across time and thus provides insight into the way that people may think more generally.

5.8: Limitations

One of the main limitations is the potential lack of power of emotional words in the early AOA condition. This occurred because there are a limited number of words that have high arousal, early AOA, and are abstract -- unsurprisingly, most words children learn early in life are not abstract, and they also tend to be relatively short in length (Kousta et al., 2011). Thus, essentially every word was used when balancing the groups, and still only had 50 per group. For an EEG study, and for early fast moving components, this is a relatively small number (Luck, 2014). There are also relatively few abstract words that have high arousal in the late AOA condition, apart from words associated with sex and relatively recent curse words. Since it would not be idea to have a set of words where a small number of semantic categories were overly represented, which can cause category effects, this again limited the number of stimuli that could be used and hence power of the study.

5.9: Future directions

This study has yielded interesting results regarding the effect of AOA on processing emotional language. Further studies could investigate the reasoning behind the lack of an EPN response. It would be interesting to compare these results to other modalities, notably spoken words, which can also capture attention (Grass et al., 2016). This way identical words could be used but the ecological importance of them would differ – i.e., there would be a comparison between reading, which is a non-innate task that one must learn, and spoken language, which is innate and most people learn without problems (Grass et al., 2016).

5.10: Conclusion

The present study aimed to investigated electrophysiological correlates of language processing regarding age of acquisition and emotion. It was confirmed that early AOA words were processed more efficiently than late AOA words, but contrary to expectations, early AOA words with emotional characteristics produced a more negative going N400 than late AOA words with emotional characteristics. This suggests that early AOA emotion words have stronger semantic associations compared to late AOA emotion words. Interestingly, there was no EPN effect, which is commonly detected in emotional attentional capture studies. This is a possible confound in previous written word studies that causes EPN to look greater than it actually is.

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Appendix A: SONA Advertisement, Complete Information Sheet, Consent Form

Examining the effect of age of acquisition on the processing of words using electroencephalography?

This study will be examining the extent to which the age of acquisition of words (when you first learnt them) effects the way you read them. We will be using electroencephalography (EEG) to measure the electrical signal from your brain when you do this. This involves putting a cap on your head and gel in your hair so the signal can be measured. This is entirely harmless.

The entire procedure from start to end where we put the electroencephalography cap on, run the study, and clean your hair can take over 2 hours (typically less). If you are a first year psychology student you will be awarded 4 hours of credit for research participation. We will also compensate you with a $100 voucher for you time. If you are interested in neuroscience, I [redacted] am also happy to show you your data at a later time so you can see what we are interested in and what the data actually looks like.

Requirements:

- Must be a native English speaker
- Must not have any form of reading disorder

Note that we put the gel in your hair and attach the electrodes using something that *looks* like a syringe with a needle. The needle is not sharp and has a rounded end so it does not scratch you, and we are happy to show you this as well as let you feel for yourself. However, if you have a fear of needles and may potentially faint when you see one (which is common enough), don't do this study!

Thank you for your time!

Please email [redacted]@adelaide.edu.au to arrange a time to participate.

Participation Information Sheet

Age of Acquisition and affective words

PROJECT TITLE: Examining the effect of age of acquisition on the processing of words using electroencephalography
HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER:
PRINCIPAL INVESTIGATOR: [redacted]
STUDENT RESEARCHER: [redacted]
STUDENT'S DEGREE: Honours

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?
This project will be investigating the extent to which age of acquisition (when you first learnt a word) affects the way you read. This will be measured via the electrical signals your brain produces using electroencephalography (EEG).

Who is undertaking the project?
This project is being conducted by Dr [redacted], a member of staff in the Psychology Department, and Ms [redacted] and Ms [redacted] who are currently doing Honours in Psychology.

Why am I being invited to participate?
You are being invited as you are part of the University of Adelaide's first year psychology research participation pool or via word-of-mouth.

What am I being invited to do?
You are being invited to undertake a task that involves reading a list of words whilst wearing cap with electrodes in it so we can measure the electrical activity your brain creates.

How much time will my involvement in the project take?

The task itself takes about 25 minutes. However, explaining everything, putting the cap on which will measure your brain's electrical activity, which includes putting gel in your hair so there is a connection between your scalp and the electrodes in the cap, and cleaning your hair may take over 2 hours (typically less).

Are there any risks associated with participating in this project?

No. However, please note that putting the cap on means we have to put gel in your hair and rub your scalp slightly to get a good connection between your scalp and our electrode. This is done with what looks like a syringe and needle. This needle is **not** sharp – we are happy to show you and give one to you so you can feel it yourself – it has a rounded end so it cannot hurt you. However, if you are likely to faint when seeing a needle, as is common enough, don't do this study!

What are the potential benefits of the research project?

The benefits to participant include: (1) Learning something about reading; and (2) Learning something about experimental design. If relevant, you will also fulfil a requirement of their 1st year psychology course and be credited with 2.5 hours of research participation. You will also get paid for you time ($100). I [redacted] am also happy to show you your data at a later time if you are interested in neuroscience. If you are in first year, this should give you a much better idea of the practicalities of running an EEG study and what the data really looks like, rather than just seeing stuff that often looks perfect in journal articles (but never really is!).

Can I withdraw from the project?

Age of Acquisition and affective words

Participation in this project is completely voluntary. If you agree to participate, you can withdraw from the study at any time.

What will happen to my information?
In terms of the task data, your responses will be recorded for later analysis. These responses will be kept on a private computer in an encoded form for at least 5 years. Any responses that involve any written form (including the consent form) will be stored in a locked cabinet in a locked room. Your results from this study are completely anonymous and confidential, and your data will be tagged with a number so that it cannot be identified even by the person processing the data. No individuals will be identified if the results of this study are published in a scientific journal or any other way. Once group results have been calculated, they will be made available to you upon request. Findings from this project may be presented in the form of a fourth-year (honours) psychology thesis. In addition, findings may be published in an academic journal or presented at a conference.

Who do I contact if I have questions about the project?
Although unlikely, participation in this study may raise issues of concern for you. If you would like to speak to a counsellor free of charge, please contact the University of Adelaide Life Counselling Support on (08) [redacted]@adelaide.edu.au.

If you wish to ask any further questions about this project, either before you have participated or after you have participated, you can by contacting Senior Lecturer [redacted] at the following address:

Dr [redacted]
Ph: +61 [redacted]
[redacted]@adelaide.edu.au
Faculty of Health and Medical Sciences (Psychology)

What if I have a complaint or any concerns?
This study has been approved by the Human Research Ethics Committee at the University of Adelaide. This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research 2007 (Updated 2018). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. If you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant, please contact the Human Research Ethics Committee's Secretariat on:

Phone: +61 [redacted]
Email: [redacted]@adelaide.edu.au
Post: [redacted]
Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

If I want to participate, what do I do?
If you are interested in participating in this study, please use the SONA system to book a time to complete the study. Alternatively, email [redacted]@adelaide.edu.au and I can organise a time.

Yours sincerely,
Dr [redacted]
Ph: +61 [redacted]
[redacted]@adelaide.edu.au
Faculty of Health and Medical Sciences (Psychology)

Age of Acquisition and affective words

INFORMED CONSENT

Project Title: Examining the processing of words using electroencephalography
Principal Investigator: [redacted]
Student Investigator:

1. **Consent**
I consent to participate in the project named above. I have been provided a copy of the project information statement and this consent form and any questions I have asked have been answered to my satisfaction.
YES NO

2. **Please answer the following questions:**

I agree to provide my basic demographic information	YES NO
Do you have normal/corrected-to-normal vision?	YES NO
Are you a native English speaker?	YES NO
What is your gender?	M | F | Other
What is your age?	____________
Do you have any form of reading disorder?	YES NO

When you do these tasks, which hand do you use (tick)

	Always left	Usually left	Both Equally	Usually right	Always right
Writing					
Throwing					
Use a toothbrush					
Use a spoon					

3. **I acknowledge that**
- Possible risks have been explained to me to my satisfaction.
- My participation is voluntary and that I am free to withdraw from the project at any time without explanation.
- The project is only for the purpose of research and not for profit.
- Any personal or health information about me which is gathered in the course of and as a result of my participating in this project will be collected and retained for the purpose of this project and accessed and analysed by the researchers for the purpose of conducting this project.
- My anonymity is preserved and I will not be identified in publications or otherwise without my expression of written consent.
- This data may be used in future research.

By signing this I agree to participate in this project.
Name of Participant: _________________
Signature: __________________________
Date: ______________________________