Examining the Embodiment of Language

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Keith O`Donnell B.A. (Hons)

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Research Supervisors: Prof. Seán Commins (MU)/Dr. Patricia Gough (UCD)

Head of Department: Prof. Michael Cooke

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Chapter 1

General Introduction

1.1 Theories of language processing

The ability to process written language is one of the few features that differentiate humans from all other species (Pinker, 1994). However, precisely how language is processed has long been the subject of healthy debate. For example, traditional models proposed that language processing was an *amodal* phenomenon that centred around the mental manipulation of abstract symbols (Bedny et al., 2012; Fodor & Pylyshyn, 1988). Generally, at the crux of these theories and other similar ones (see Bedny & Caramazza, 2011) is the proposition that language representation is abstract and distinct from the physical experience/s to which the language refers. Arguably, neuroanatomically, many of these theories closely align with the Wernicke-Geschwind Model, which proposed that language production primarily involves the inferior frontal area (i.e., *Broca's area*), while language representation/comprehension involves the superior temporal area (i.e., *Wernicke's area*) (Geschwind, 1972; Wernicke, 1874 – see Figure 1.1). However, there are many additional brain areas involved in language processing (and production), and this has changed the way many view the representation of language.

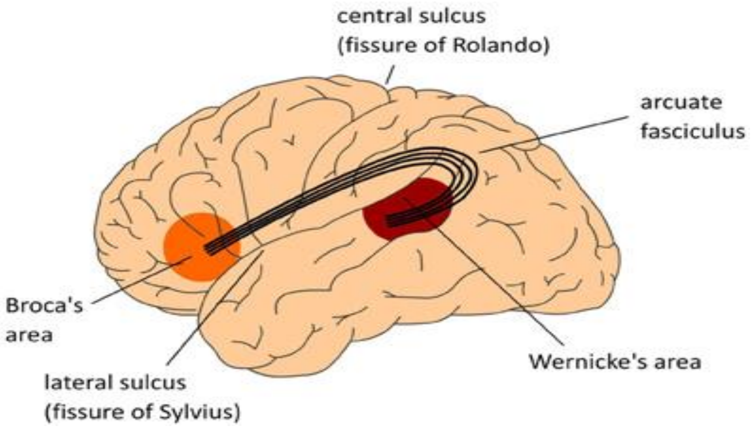

Figure 1.1. The classical language model, which proposed that language production involves Broca`s area, while language comprehension relies upon Wernicke's area. The arcuate fasciculus enables connections between the two areas. Image adapted from Hagoort (2013).

In contrast to classical models, theories of *language embodiment* assert that language and experience are inter-related and that processing language is grounded in the experience of the actions, objects, or events to which the language refers (see Andres et al., 2015; Barsalou, 1999; Buccino et al., 2018; Gallese, 2008; Gianelli et al., 2020; Glenberg & Gallese, 2012; Gough et al., 2013; Marino et al., 2011; Pulvermüller, 2005; Zarr et al., 2013). Central to embodiment theories is the proposition that the representation of language *is* closely related to the experience of what the language describes (Barsalou, 1999; Buccino et al., 2018; Gough et al., 2013; Marino et al., 2011). As will be discussed throughout the general introduction, there is much evidence to support this claim, and there is also some evidence to oppose embodied theories, too. However, though the idea of grounded cognition has been around for many years (Barsalou, 2010), the rapid development of embodied theories of language, from which numerous hypotheses have been tested, can be traced back to the discovery of particular types of neurons in macaque monkeys` brains – mirror neurons. For many, the discovery of these neurons led to the realisation that the Wernicke-Geschwind model was incomplete and that language processing was closely linked to action perception (Tremblay & Dick, 2016).

Mirror neurons were first discovered in the F5 premotor area of a macaque monkey (di Pellegrino et al., 1992) – a region which is anatomically close to Broadman`s area 44 (i.e., Broca`s area) in humans. Specifically, it was found that certain F5 premotor neurons fired when the monkey observed an experimenter grabbing an object (i.e., a piece of food) and when the monkey later performed the same precise action. However, interestingly, the neurons did not fire when the monkey was simply presented with the food on a tray or when the experimenter moved towards the food. di Pellegrino et al. (1992) concluded that these specific F5 neurons must subserve a basic semantic system in the macaque premotor cortex – the purpose of which was to understand others` actions and to facilitate the production of the same actions. Later, mirror neurons were also discovered in the macaque inferior parietal lobule

(IPL) (Fogassi et al., 2005) – a region which is associated with many functions including the perception of bodily limb positions and reaching towards objects (Rizzolatti et al., 2006). In addition, macaque parietal mirror neurons were found to function in a similar manner to F5 premotor ones (Ferrari et al., 2003; Fogassi et al., 2005). Explicitly, it was found that neurons in the rostral section of the IPL discharged when the monkey grasped a piece of food and when the same action was observed. However, Fogassi et al. (2005) also found that one set of IPL neurons fired only when the food was eaten or observed being eaten, while another set of neurons fired only when the monkey placed the food into a container or watched the experimenter perform the same act. Thus, macaque parietal neurons not only fire during general motor acts and action observations; they also appear to encode and subserve more specific motor acts, which was also confirmed in a study by Breveglieri et al. (2019). Overall, the evidence seems to suggest that mirror neurons in the macaque frontal and parietal regions underpin an action understanding system – grounded upon a link between the perception of others` actions and the execution of the corresponding actions (Rizzolatti, 2004; Gallese, 2008).

The discovery of a similar mirror system in human motor cortex resulted from an early study conducted by Fadiga et al. (1995). Here, participants had to observe an experimenter grasping a 3D object, looking at the object only, and tracing figures in the air with their hand. Participants` left primary motor cortex was also stimulated using transcranial magnetic stimulation (TMS). This procedure involves applying an electrical current to the layers of the cortex, via a magnetic coil, to generate a magnetic field and excite nearby neurons (Lefaucheur, 2019). If primary motor cortex is stimulated by TMS, the resulting neural excitation can be examined by measuring resulting electrical signals known as motor evoked potentials (MEPs) from muscles in the body (Chail et al., 2018). Accordingly, the MEPs that result from motor stimulation can provide valuable data about the motor pathways elicited by concurrently presented stimuli and the site of stimulation (Ostarek, & Huettig, 2019; Legatt (2014).

In the Fadiga et al. (1995) study, MEPs were examined from four hand muscles – the extensor digitorum communis (EDC), flexor digitorum superficialis (FDS), first dorsal interosseus (FDI), and opponens pollicis (OP) – muscles associated with object manipulation, flexing the fingers, moving the fingers away from the midline of the hand, and rotating the thumb, respectively. During the grasping observation condition, it was found that MEP amplitude increased in all muscles, which suggested that the motor neurons underpinning the production of a hand action also fire while the same action is being observed. Additionally, during the action observation condition (i.e., tracing the air), increased MEP amplitude was found in all except the OP muscle (Fadiga et., 1995). Thus, in this condition, an increase in motor activity was only found in muscles that participants usually use to perform the actions that they observed. These findings and others (e.g., Kilner, et al., 2009; Mukamel, et al., 2010) suggest the existence of an action mirroring system in human motor regions. F

There is also evidence to show the presence of mirror neurons in human parietal regions. For example, Chong et al. (2008) conducted an experiment which required participants to observe a hand performing different transitive actions (e.g., lifting a bag, opening a lid). Participants were also required to perform the same actions, and the neural correlates of action observation and execution were measured using a technique called functional magnetic resonance imaging (fMRI). fMRI is a neuroimaging tool that works by detecting localised changes in blood flow in the brain (Heeger & Ress, 2002). Specifically, red blood cells carry oxygen to neurons, and when neural activity increases in a brain area, more oxygen is needed. Thus, when a participant performs a task, and a brain area is engaged in the task, there should be an increase in oxygenated blood flow in that area (Heeger & Ress, 2002; Glover, 2011). Consequently, fMRI can be a viable means of establishing which brain areas are most activated during a language processing task and/or an action-related task.

During the hand observation and execution tasks, Chong et al. (2008) found overlapping brain activity in regions such as the supramarginal gyrus (SMG) and notably, the IPL. Accordingly, this suggests that the human IPL may also contain neurons that both encode and subserve specific bodily actions. Overall, therefore, there is ample evidence to suggest that mirror neurons in frontoparietal regions represent an action understanding/execution system in humans. Interestingly, a related but separate class of neurons related to action observation and execution have also been observed in primates` frontoparietal areas – called canonical neurons (Fadiga & Craighero, 2003).

Canonical neurons are a separate class of cells found in the rear section of macaque F5 premotor cortex and subsequently found in human premotor and parietal areas (Fadiga & Craighero, 2003; Garbarini & Adenzato, 2004). Moreover, canonical neurons differ to mirror neurons in that they fire during actions and during observation of 3-dimensional objects but not during action observation (Garbarini & Adenzato, 2004). Interestingly, canonical neurons have also been found to discharge while observing objects with similar characteristics to a target object, which suggest that an object`s representation must also include the associated functions that can be performed. This proposition is closely linked to Gibson`s (1979) concept of affordances, which proposed that objects afford their use, as their features imply the means by which one can interact with them. Such affordances can be seen in relation to everyday objects; for example, a door handle implies that it needs to be pushed up/down, while a cup handle implies how the object should be grasped. Canonical neurons, which fire while observing and acting upon objects with affordances, are said to subserve these interactions (Costantini, et al., 2021). Taken together, canonical neurons and mirror neurons – via a frontoparietal circuit – appear to underpin an action observation and execution system that centres around communication between sender and receiver (see Figure 1.2). It has been posited that humans` ability to process language resides within these same systems (Fogassi & Ferrari, 2016; Gallese, 2008; Marino et al., 2001, 2014).

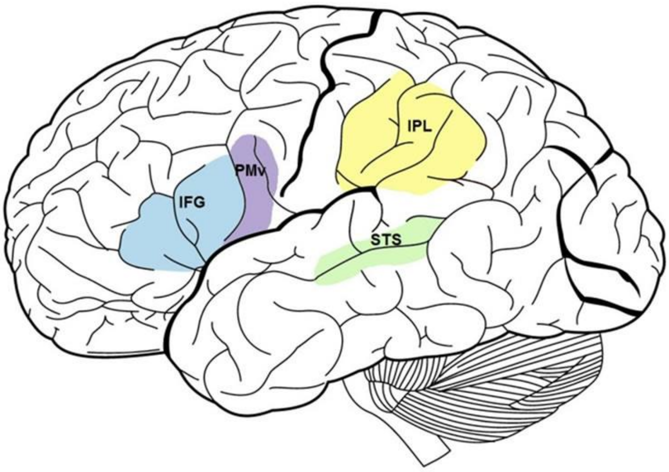

Figure 1.2. The human frontoparietal mirroring system. IFG = inferior frontal gyrus; PMv = ventral premotor area; IPL = inferior parietal lobule; STS = superior temporal sulcus. Adapted from Julie et al. (2012).

Specifically, according to Fogassi and Ferrari (2016), the shared frontoparietal sensorimotor programs between sender and receiver allow agents to both produce and receive messages. Moreover, these messages centre around object manipulations and the perception and execution of bodily actions (Foggasi & Ferrari, 2016; Gallese, 2008). However, the system, though similar in non-human and human primates, is said to be used for different social purposes (Gallese, 2008; Rizzolatti & Craighero, 2004). For non-human primates, the mirroring system typically facilitates interspecies communication primarily based upon understanding others` calls and behaviour. Contrastingly, in humans, this has evolved to also include understanding and producing words and phrases that describe associated actions and objects – a claim which is at the forefront of many embodied language theories (Buccino et al., 2005, 2018; Fogassi & Ferrari, 2016; Gallese, 2008; Marino et al., 2001, 2014; Rizzolatti &

Craighero, 2004). Furthermore, it is a claim that has found much support – via studies that have shown that certain aspects of human language processing activate and use frontoparietal mirroring regions. One common method to test the phenomenon has been to examine cortical motor activations while language referring to actions (verbs) and objects (nouns) is processed. If, as proposed, language representation is related to action experience, then processing language referring to bodily actions or objects upon which the body can act should potentially activate the neural areas that underpin the production of the associated act. As will be discussed over the next few sections, there is much evidence to support this assertion.

1.2 Neuroimaging support for embodied theories of language

Support for the claim that processing verbs describing bodily actions activates the neural areas that underpin the bodily actions was provided via early embodiment studies on single word processing – such as by Hauk et al. (2004). Here, the researchers used fMRI to examine cortical activity while participants read words describing different actions performed with different body parts. The Hauk et al. (2004) experiment found that reading words referring to hand actions (e.g., *to wash*), foot actions (e.g., *to kick*) and face actions (e.g., *to lick*) all activated the left inferior temporal lobe – the classically defined language processing area. However, it was also found that the different hand and foot action word types activated the specific regions of left premotor and primary motor cortex that are involved during actual hand and foot actions, respectively. This latter finding suggests that processing a verb describing a bodily action also activates the precise neural area that underpins the production of the action – implying that the representation is closely related to the action described. Further support for this idea was observed in a 2010 study by Willems et al. Here, participants` processing of manual (i.e., *smack*) and non-manual action words (i.e., *dictate*) was tested as they underwent fMRI. The results from the Willems et al. (2010) study also showed that manual action words activated areas in left premotor and primary motor cortex, whereas the non-action words did not. Overall, both studies` findings imply that processing language referring to specific actions uses the precise neural areas that underpin the production of the action – suggesting that action word representation could be related to the action described in the language.

Similar motor activity has also been observed during neuroimaging studies which have tested the neural basis of verb processing within sentences. For instance, Tettamanti et al. (2005) conducted an fMRI experiment to examine participants` cortical activity while hand-, foot-, and mouth-related sentences were processed. The study found that reading sentences such as *I grasp a knife, I kick the ball,* or *I bite an apple* activated the corresponding hand, foot, and mouth areas in left premotor cortex, respectively. Later, Wang et al. (2019) conducted a sentence processing study using a different neuroimaging method than fMRI. Specifically, Wang et al. (2019) used electroencephalography (EEG), which is a non-invasive neuroimaging tool that can be used to measure the brain`s electrical activity in response to an event of interest or a task (Blinowska & Durka, 2006). In EEG research, the N400 relates to a cluster of brain activity, or a component, that begins approximately 400 milliseconds (ms) after stimulus presentation in response to congruent/incongruent stimuli (see Chapters 2 and 6 for more details); typically, larger N400s are related to processing incongruent stimuli (Kappenman et al., 2021). In the Wang et al. (2019) study, participants` brain activity was examined as they processed two-part sentences containing either congruent hand actions (e.g., *Xiao Zhang rolled the dough and then wrapped the dumplings*) or incongruent hand actions (e.g., *Xiao Zhang rolled the dough while wrapping the dumplings*). The results showed that incongruent sentences, describing two concurrent motor actions, elicited greater N400 activity in comparison with processing congruent motor sentences. This finding implies that it is more difficult for the brain to process action-related stimuli that are incongruent with motor programs – again, suggesting that processing action words is related to the actual actions described.

Taken together, evidence from neuroimaging studies of verb processing appear to support the claim that processing language referring to specific bodily actions activates the exact motor areas that underpin the production of the actions described. This suggests that action verb processing could be related to the action described by the verb.

There is also evidence to show that processing nouns referring to objects upon which the body can act involves the precise cortical areas that are associated with the motor act. For instance, Dreyer et al. (2020) conducted a study with neurotypical controls and two different groups of neural patients – one of which had lesions to dorsal precentral, postcentral and IPL regions, and one with lesions to temporal and/or inferior frontal areas. Patient studies provide valuable insight into the importance of a given region for the performance of a task (Buccino et al., 2018; Dreyer et al., 2020). If, for instance, a lesioned area is needed to process a stimulus, then the patient should show some type of impairment relative to control participants, which would also suggest a casual role for the affected area. In the Dreyer et al. (2020) study, a lexical decision task (LDT) was employed, which required participants to process nouns referring to tools (e.g., *spoon*), animals (e.g., *sheep*), and foods (e.g., *pea*) as well as pseudo nouns (i.e., nonsense words); participants were required to respond (via button press) as quickly as possible when a presented stimulus was a real word. The findings showed that patients who had lesions to dorsal pre- and postcentral sensorimotor areas were significantly impaired during recognition of tool nouns. However, patients with lesions to temporal or inferior frontal areas were not impaired during the processing of any noun types – nor were neurotypical control participants (Dreyer et al., 2020). This evidence suggests that damage to frontoparietal regions which subserve object interactions impairs one's ability to process words related to the objects. Relatedly, this implies that the specific sensory and motor areas associated with manipulating objects are also involved in processing words referring to objects – further highlighting that language and action experience could be inter-related.

Additional support for action-related nouns being represented in the sensory and motor areas was provided via an earlier Desai et al. (2016) study, which used fMRI with two separate groups of participants who were required to read two separate short texts (e.g., The Emperor’s New Clothes). Sections of written texts also contained nouns – some referring to manipulable objects and some which did not; neural activity was examined while both sets of nouns were processed. The results found that processing manipulable nouns was correlated with increased neural activity in the posterior inferior temporal areas and the anterior inferior parietal (aIPL) areas – the aIPL being one of the brain areas involved in planning and producing manual actions, such as reaching and grasping (Desai et al., 2016). Taken together, these findings and more recent ones (e.g., Visani et al., 2022) suggest that the brain areas involved in planning and performing motor acts are also involved in processing nouns related to those acts.

Overall, neuroimaging findings from verb and noun studies suggest that the frontoparietal mirror regions are involved in processing language referring to bodily actions and objects, which implies a close link between the action/object described and the corresponding representation. Accordingly, this adds further weight to the claim that language and action are inter-related – and not amodal – and that processing language is an embodied phenomenon. However, in addition to neuroimaging studies, the link between language processing and action experience has been tested behaviourally and via brain stimulation work, and findings from these studies have provided further evidence in support of embodied language theories. Moreover, behavioural studies have the advantage of being able to test how processing motor-related language can impact upon corresponding motor behaviour. Brain stimulation studies are also beneficial, as they can provide knowledge about motor pathways elicited by stimuli and the site of stimulation (Ostarek, & Huettig, 2019; Legatt (2014) and can sometimes determine causality between a given stimulated region and a corresponding task (e.g., Repetto et al., 2013).

1.3 Behavioural and brain stimulation studies of motor-related language

Evidence for embodiment theorists` claims that language and action are inter-related has also come from the many behavioural experiments and brain stimulation studies that have tested motor responses to verb and noun processing. Typically, verb experiments have shown that processing verbs performed with specific body parts can modulate response times (RTs) that are performed with the corresponding body part (see Buccino et al., 2005; Boulenger et al., 2006; Mirabella et al., 2012; Repetto et al., 2013; Andres et al., 2015; Gianelli et al., 2020). Moreover, as with neuroimaging studies, evidence of motor modulation has been found in relation to processing single action words and action sentences. In a classic single-word behavioural study, Sato et al. (2008) presented participants with hand-related verbs (e.g., *to applaud*), foot-related verbs (e.g., *to walk*), and abstract verbs (e.g., *to love*) – participants were required to perform a hand response (i.e., press a knob) to concrete but not abstract stimuli. The study found that when participants were required to perform an early response (i.e., after 200 ms), hand RTs were significantly slower during the processing of hand-related verbs – relative to foot-related verbs. The researchers suggested that interference occurred, as the motor system was tasked with processing the hand-related word and executing a simultaneous hand response (Sato et al., 2008) – implying that processing the verb is closely related to the action described by the verb.

A later study by Fernandino et al. (2013) provided further support for the claim that processing action words is closely related to the action described. Again, this study used a patient sample to show how damage to the sensorimotor system can impair the processing of sensorimotor language. Specifically, the researchers compared action verb processing in Parkinson`s Disease (PD) patients and control participants. Generally, PD patients are typified by disruption to motor/premotor and parietal circuits – areas involved in object interactions – so examining their processing of motor-related stimuli allows researchers to establish the degree to which motor areas are involved in processing motor-related language (Buccino et al., 2018; Fernandino et al., 2013). Two different tasks were employed by Fernandino et al., 2013 – a lexical decision task (LDT), which presented action (e.g., *to squeeze*) and abstract verbs (e.g., *to depend*) and required participants to perform a hand response to real words and pseudo words. A semantic similarity judgement (SSJ) task was also utilised; this required participants to decide (via hand response) which of a set of words was most similar to a target word. The LDT results showed that the PD patients had significantly slower RTs during trials with action verbs vs. abstract verbs, whereas the action verbs elicited significantly quicker RTs in controls. Additionally, it was found that the PD patients were significantly less accurate in the SSJ task. These findings suggest that motor-related behaviour while processing motor language is disrupted when sensorimotor regions are impaired – implying a causal link between sensorimotor regions and processing language related to bodily actions.

Evidence of a causal link has also been shown in a study by Repetto et al. (2013) – via the brain stimulation method, repetitive transcranial magnetic stimulation (rTMS). According to the authors, rTMS functions by virtually deactivating a stimulated brain site for a period; researchers can then examine the importance of the deactivated site for the task at hand (Repetto et al., 2013). In the experiment, rTMS was applied at a frequency of 1 hertz (Hz) to left or right primary motor cortex for a period of 12 minutes, before participants were presented with hand-related verbs (e.g., *to catch*) and non-hand related verbs (e.g., *to fail*). The participants` task was to decide (via right-hand button press) on the concreteness of presented stimuli, and the analyses found significantly slower responses to hand-related verbs after left hemisphere stimulation only (Repetto et al., 2013). Again, this result shows how disrupting left primary motor cortex impairs subsequent processing of hand-related language, which suggests that the region is involved in processing words referring to hand-related actions.

Evidence of verb processing has also come from behavioural and brain stimulation studies that have tested sentences. For example, an early study by Buccino et al. (2005) presented participants with sentences expressing hand-related (e.g., *he wrote the essay*), foot-related (e.g., *he kicked the ball*), and abstract actions (e.g., *he enjoyed the sight*); participants were required to respond, either with the hand or foot, when a concrete action was expressed. The results showed that foot-related sentences elicited significantly slower RTs in those who were required to perform foot responses, while hand-related sentences elicited significantly slower hand RTs. Buccino et al. (2005) posited that this resulted because the body-specific motor activity elicited by the sentences interfered with the production of the subsequent body-specific motor response. Interestingly, with a separate group of participants, Buccino et al. (2005) ran the same experiment using TMS – providing another means of examining the impact of motor-related sentences on motor activity.

Explicitly, the Buccino et al. (2005) study recorded MEPs from the right hand (*opponens pollicis* and first dorsal *interosseus* muscles) and foot (*tibialis anterior* and *gastrocnemius* muscles) muscles, respectively. The results showed that MEPs were reduced in the *opponens pollicis* and first dorsal *interosseus* muscles, only, when hand-related sentences were processed. Additionally, reduced MEPs were found in the *tibialis anterior* muscle (used to perform the actual foot action), only, while foot-related sentences were processed. Both findings suggest that words referring to actions performed with specific body parts excite associated motor regions, which can modify subsequent actions performed with the same body part. Overall, this provides further evidence for the claim that language and action are inter-related.

The effect of motor-related sentences on motor behaviour has also been examined in other ways. For instance, a study by Zarr et al. (2014) found that processing sentences that describe hand actions performed in a certain direction (i.e., toward the body) interfered with participants` observations of hand actions being performed in the same direction. The same interference was not observed after participants viewed hand actions that were being performed away from the body or leg actions performed in either direction. Interestingly, a study on verb processing by Shebani and Pulvermüller (2013) showed that the relationship between language and motor activity can be bi-directional, in that motor performance can influence subsequent language-related activity. In their experiment, Shebani and Pulvermüller (2013) presented participants with a series of four arm-related words (e.g., *clap*) or leg-related words (e.g., *step*), and participants were required to keep the words in memory for a period of 6 seconds. In one condition, the requirement was simply to repeat the words, when prompted, while in another condition, participants were required to repeat the words by sounding out their syllables. Two further conditions involved tapping out either a foot or a hand sequence whilst attempting to repeat the words. The experiment found significantly more errors with arm-related words when participants had to perform the hand-related tapping sequence (Shebani and Pulvermüller, 2013). Similarly, significantly more errors were found whilst trying to recall leg-related words during the leg tapping sequence. These findings highlight the influence that motor activity can have on language processing, and production, via an inhibition to subsequent performance.

However, behavioural experiments have also found that processing bodily specific verbs can prime motor responses performed with the body part described in the actions (see Boulenger et al., 2006; Klepp et al., 2017). The difference between motor impairment and enhancement is often the result of task demands and the time point within which a participant is required to respond (see Chapter 3). For example, the Boulenger et al. (2006) study found significantly quicker hand RTs towards a target were when responses were performed approximately 550 ms after hand-related verbs were presented. Klepp et al. (2017) also found that processing hand-related and foot-related verbs primed subsequent hand and foot motor responses, respectively, that were performed from 400 ms onwards after verb presentation.

These facilitatory motor effects are said to result because the hand and foot cortical motor areas have become activated during the processing of the hand- and foot-related words, and the prior motor activation primes the subsequent motor responses (Boulenger et al., 2006). In sum, processing action words appears to be related to experiences of the actions described by the words, and this can either impede or facilitate motor responses performed with the corresponding body part. Overall, this suggests that processing verbs describing bodily actions activates and uses the same neural substrates that subserve the production of the bodily actions – and that language and motor experience are interlinking processes.

Behavioural experiments have also tested the impact of processing nouns on motor behaviour. For example, a study by Glover et al. (2004) presented participants with words (nouns) referring to small, hand-related objects (e.g., *pea*) and words referring to larger, hand-related objects (e.g., *jar*). Participants were required to read the words silently before grasping a small, rectangular wooden block between 4-6 cm long and repositioning it approximately 10 cm in front of themselves. The outcome variable was participants` grip aperture (i.e., the distance between the thumb and forefinger), which was measured via a motion-tracking machine. The results showed that grip aperture was larger during trials containing larger object words, which suggests that the precise motor representation elicited by processing the word impacted the subsequent grasping action (Glover et al., 2004). A later study by Marino et al. (2011) also tested the effect of hand-related nouns on motor performance. Here, participants were presented with nouns referring to hand-related objects (e.g., *pencil*), foot-related objects (e.g., *pedal*), and abstract entities (e.g., *jealousy*), and they were required to perform a hand response (one group with the left hand, one with the right), via button press on a computer keyboard, when the stimulus described a concrete noun. Further, the signal to respond was either presented early (i.e., at 150 ms) or late (i.e., at 1150 ms) after noun presentation. At the early signal, Marino et al. (2011) found that those who responded with the right hand had significantly slower hand RTs during hand-related trials. This suggests that the representation of the hand-related word impeded a subsequent hand response. Interestingly, those who responded with the left hand had significantly quicker hand RTs during trials with hand-related nouns, while no effects were found at the late signal. Taken together, the Glover et al. (2004) and Marino et al. (2011) findings further support the claim that processing hand-related nouns can interfere with motor acts and that this interference is specific to the left hemisphere.

Later, Buccino et al. (2018) conducted a study with PD patients and neurotypical controls. As discussed, typically, PD patients have impairments to motor and parietal areas caused by disruptions to the nigro-striatal pathway, which affects their ability to interact with objects (Buccino et al., 2018). In the Buccino et al. (2018) experiment, hand-related nouns (e.g., *leaf*), non-hand related nouns (e.g., *cloud*), and pseudowords were presented – as were images of hand-related nouns, non-hand related nouns, and scrambled images. Participants were required to perform a hand response when the stimulus was a real object. The results showed that controls had significantly slower RTs while processing hand-related nouns and pictures of hand-related nouns, but no such modification occurred in the PD patients (Buccino et al., 2018). Reasonably, it could be argued that PD patients, who have motor impairments, also have an impaired ability to discriminate motor-related nouns. At the very least, this suggests that the motor circuits play an important role in processing language related to motor activity. Potentially, it also suggests that the affected areas must form part of the semantic processing circuit.

1.4 Criticisms of embodied theories

Overall, there is much evidence to imply that sensory and motor regions, comprised within the frontoparietal mirroring circuit, are involved in language processing (Andres et al., 2015; Barsalou, 1999; Buccino et al., 2018; Gallese, 2008; Gianelli et al., 2020; Glenberg & Gallese, 2012; Gough et al., 2013; Marino et al., 2011; Pulvermüller, 2005). Additionally, evidence from a broad range of neuroimaging, behavioural, and brain stimulation studies has suggested that the interaction between processing action-related language and motor activity can be observed in numerous ways. Moreover, evidence from these studies, and from patient studies, has suggested that the sensory and motor regions could be causally involved – elucidated by the findings that damage to regions within the sensorimotor circuit can impair the processing of sensorimotor language. Given the breadth of findings, it seems reasonable to suggest that there is substantial support for the claim that language and action are inter-related and language processing is an embodied process.

However, there are still some who dispute the proposition that language and action are inter-related and that language is an embodied phenomenon (e.g., de Zubicaray et al., 2013; Hickock, 2014; Mahon & Caramazza, 2005; Papeo et al., 2009). Some of these criticisms have resulted from experimental findings which have found that non-sensorimotor words can also activate sensory and motor areas. For instance, de Zubicaray et al. (2013) ran an fMRI study which presented participants with hand-related verbs, non-hand related nouns, and pseudo words containing endings that were similar to real verbs and nouns. Participants were required to perform a hand response depending upon whether or not they judged the stimulus as a noun or a verb. The study found that hand-related verbs and verb-like pseudowords elicited increased activity in left supplementary motor area (SMA) and mid lateral primary motor cortex (de Zubicaray et al., 2013) – non-hand related nouns and noun-like non words did not elicit increased activity in these regions. The researchers proposed that pseudo word motor activations (and indeed motor activity found in many embodiment experiments) reflects the motor cortices` role in discriminating grammatical categories (i.e., verbs from nouns). However, this claim does not seem sufficient to explain the many findings which have shown that processing hand-related verbs (see Boulenger et al., 2006; Buccino et al., 2005; Klepp et al., 2017), hand-related nouns (see Marino et al., 2011, 2014; Zhang et al., 2016), and even hand-related adjectives (see Gough et al., 2013) all activated and utilise the hand motor area – regardless of grammatical category.

Additionally, the non-word motor activations in the de Zubicaray et al. (2013) study were arguably due to the task employed. For example, the pseudo words contained endings that were graphemically similar to hand-related verbs, and participants were required to make grammatical category judgements on all presented stimuli. It is feasible that the verb-like characteristics of the pseudo words would become salient in this instance, which would quite possibly result in motor region excitation. It is also noteworthy that the study used fMRI – which, as discussed, can be useful for establishing brain regions that are utilised for a task. However, fMRI measures oxygenated blood flow, which takes time to change from one area to another (Luck, 2014), so it does not allow one to determine the time at which the brain region came online or whether or not the region was causally involved in the task. Though some of the embodiment evidence presented so far has been taken from fMRI research, there has also been ample evidence from EEG, behavioural, patient, and TMS studies – the latter occasionally allowing for testing causality (i.e., rTMS). A similar pseudo word finding using one of these methods would be much more of a concern for embodied language theorists. Relatedly, Gianelli et al. (2020) conducted a series of experiments – one of which found that pseudo words (and scrambled images) did not modulate arm MEPs whereas hand-related nouns (e.g., *pen – to write*) and pictures illustrating the same actions did. These findings imply the motor regions are not actually needed to process pseudo words, which calls into question the claims of de Zubicaray et al. (2013).

Additionally, one of the ongoing debates around motor-related language centres around the representation of abstract concepts. For example, many have posited that if language is based upon sensory and motor experience, what is the nature of abstract word representations which contain no sensory or motor content; are they disembodied? (e.g., Hickock, 2014). However, there is evidence to suggest that abstract word processing may still involve sensorimotor areas – to a lesser degree than action and object words. For instance, in a study by Sakreida et al. (2013), sentences containing concrete/abstract verbs and nouns were presented to participants. One group of sentences contained a concrete verb and a hand-related noun (e.g., *to draw a butterfly*), while another contained the same hand-related noun with an abstract verb (e.g., *to marvel at a butterfly*). Additionally, another group of sentences contained the same hand-related verb with a non-hand related noun (e.g., *to draw a sunset*), while another contained the same non-hand related noun with an abstract verb (e.g., *to marvel at a sunse*t). Participants simply had to read the sentences whilst undergoing fMRI, and the researchers examined the corresponding neural activity. Sakreida et al. (2013) found that all sentence categories activated a cluster of brain areas including the left precentral and SMA areas, which appears to suggest that sensory and motor areas are involved in processing some abstract stimuli. However, interestingly, a concrete vs. abstract sentence contrast showed that concrete sentences also activated the frontoparietal network that has been shown to be involved in processing bodily specific verbs and nouns. Additionally, it was found that purely abstract sentences activated the classical left-hemisphere mid-temporal region. In sum, the results imply that abstract words may also be represented in the motor system – but specific hand-related words, regardless of grammatical category, are represented in the specific sensory and motor areas that underpin hand actions.

An earlier study by Moseley et al. (2012) also tested the degree to which abstract words may be represented in the motor system. Beforehand, the authors posited that perhaps abstract words carrying emotional meaning (e.g., *fear*) could be understood through the types of actions that are associated with the emotion (i.e., screaming, running, hitting out). Accordingly, the processing of abstract emotional words should activate the motor regions that would be used to express and respond to the emotions. In the Moseley et al. (2012) experiment, participants underwent fMRI while silently reading hand-related verbs (e.g., *grasp*), face-related verbs (e.g., *grunt*), and abstract-emotional words (e.g., *dread*). The neural analysis showed that hand-related verbs and face-related verbs activated different regions of premotor cortex – dorsolateral portion for hand words and inferior portion for face words – alongside a range of similar cortical areas (e.g., left inferior frontal gyrus, primary motor cortex). However, Moseley et al. (2012) found that abstract-emotional words also activated the joint hand- and face-related areas in addition to classical emotion regions such as the limbic system.

Coupled with the Sakreida et al. (2013) findings, the Moseley et al. (2012) work suggests that some abstract words are represented in sensory and motor areas. However, as with all fMRI studies, one must be cautious with interpretations, as it is not quite clear whether or not abstract words excite the motor system but to a lesser degree than effector-related words. However, according to Borghi et al. (2019), it is quite plausible that abstract words would be grounded in sensory and motor areas, and this is related to the means by which concrete and abstract words are acquired. For example, the concept of *a table* refers to an object one can interact with, and though there are many variations, a basic table prototype is arguably similar to many. Contrastingly, the concept of *freedom* cannot be interacted with; thus, further information and demonstration may be needed (Fini & Borghi, 2019). Accordingly, processing words such as *freedom* could be related to the verbal and physical communication that was needed to learn the concept – embodied accounts of language predict that this would involve the sensory and motor systems that learned the language through observation and/or verbal descriptions. Hence, processing abstract stimuli would activate and use the sensory and motor areas, which appears to be supported by the evidence in the preceding paragraph – though, as before, it is important to note that both studies discussed used fMRI.

Fortunately, the degree to which abstract phrases affect motor performance has also been examined directly. For instance, Kacinik (2014) carried out an interesting experiment which examined the effect of performing idioms on perception. Linguistically, idioms refer to phrases which are not meant to be taken literally – such as *sticking your neck out* or *sitting on the fence*. In the Kacinik (2014) experiment, participants had to read short narratives that centred around a fictional court case and perform the idiom described in the narrative, where applicable. For example, when reading the phrase *sitting on the edge of one`s seat*, participants had to literally sit on the edge of their seats, while reading the phrase *sticking one`s neck out* required participants to physically stick out their neck while reading. Questions were also asked in relation to excitement and risk, which are reflected in the two idioms described, potentially. The results showed that relative to control conditions, sitting on the edge of the seat increased participants` perceptions of excitement in the narrative, and physically sticking out the neck increased perceptions of risk (Kacinik (2014). The findings from this study imply that performing the actual action describing in an abstract idiom can improve perception and understanding of the described action. Accordingly, the findings suggest that abstract phrases may also be grounded in sensorimotor experience.

However, further criticism of embodied language theories has come from a recent analysis of brain stimulation findings by Solana and Santiago (2022). In the review, the authors proclaimed that it is still unclear as to whether or not the motor system is functionally involved in language processing. According to Solana and Santiago (2022), this lack of clarity has resulted from factors such as differing measures and sample sizes (many studies had *Ns* < 15); thus, further conclusive research is needed. Additionally, on a slightly more theoretical note, a review by Kompa (2021) raised some interesting points about language processing and its relation to sensorimotor experience. Here, the author proposed that embodied accounts of processing have misinterpreted some crucial functions of language. For example, as discussed, one of the main tenets of embodied accounts is the proposition that the embodiment of language allows us to understand others` actions and intentions, which has potential evolutionary and communicative value. However, Kompa (2021) declared that the point of language is to provide humans with *labels* for actions, objects, and events – which still allows us to understand but also allow us to remain distant from events. According to this logic, sensory and motor regions would be distinct from processing sensorimotor language: much evidence has been posited in dispute of this view.

Finally, a review of embodiment was conducted by Meteyard et al. in 2012, and the main points still apply currently. The review argued that theories of embodied language fall along a continuum, which ranges from *unembodied,* to *secondary embodiment,* to *weak embodiment,* and *strong embodiment.* Basically, unembodied theories of language representation refer to amodal/symbolic theories – such as the one described earlier in this chapter (i.e., Bedny & Caramazza, 2011; Fodor & Pylyshyn, 1988). Typically, these theories posit that neural processing of language does not actively involve sensory and motor areas, and word meaning is derived via relations with other words (Landauer & Dumais, 1997). Theories of secondary embodiment propose a slight relationship between sensory motor content and language representation (Meteyard et al., 2012). However, primarily, secondary theories are still amodal, as they assert that relationships are purely associative. Specifically, secondary theorists propose that during language processing, amodal, classic language areas are activated initially in a causal manner, while sensory and motor areas are activated passively, thereafter (i.e., see Mahon & Caramazza, 2008). Arguably, the evidence from patient studies that has been described thus far in this thesis suggests that sensory and motor areas may have more than a passive, secondary role in processing.

The weak embodiment stance proposes that sensory and motor information have a representational role in language processing; thus, processing *partially* depends upon the associated sensory and motor brain areas (Meteyard et al., 2012). However, these brain areas merely assist in the integration of semantic information in order to facilitate a more complete representation (see Vigliocco et al., 2004). Contrastingly, strong embodiment theories posit that semantic processing is completely dependent upon the sensory and motor areas. At the crux of this viewpoint is the claim that direct experience of a word`s referent is always simulated in sensory and motor systems (Barsalou, 1999). The findings from the current thesis should help to shed greater light on the embodied continuum.

1.5 Research gaps

There is much evidence to support the view that processing motor-related language is grounded upon the action, object, or event that the language describes. However, one reasonable criticism that could be levelled at embodiment researchers is the over-reliance on studies of verbs and nouns. As outlined, several studies have found that processing hand-related words can activate, use, and modify hand motor activity – regardless of grammatical category. Primarily, though, this phenomenon has been tested via studies on verb and noun processing only; but there are other word categories that could be related to hand action experience. For example, adjectives are words that modify nouns, and many adjectives describe properties related to approaching (e.g., *soft*) or retracting from objects (e.g., *sharp*) (Gough et al., 2013). The potential embodiment of adjectives has only been examined a couple of times previously (Garafola et al., 2021; Gough et al., 2013); thus, further testing the topic should allow for a more comprehensive account of adjective representation and the impact of a lesser studied word category on motor activity.

Additionally, while there is an extensive range of behavioural evidence to show that hand-related stimuli modify subsequent hand responses, the degree to which this is impacted by task demands and levels of processing is less clear. For instance, different studies have utilised different tasks requiring different levels of processing. Marino et al. (2011,2014) and Buccino et al. (2018) used a task requiring participants to press a keyboard button when presented stimuli described a concrete object. Contrastingly, Fernandino et al. (2013) employed an LDT – requiring participants to perform a hand response to real words and pseudo words – and a semantic similarity judgement task (SSJ) requiring a decision (i.e., hand response) as to which of a set of words was most similar to a target word. It is not quite clear if the effects from these studies are due to different levels of processing required to complete the task, and it is also an open question as to whether or not the motor activity automatically occurs in language processing or whether or not its involvement is task and/or context dependent.

Age of acquisition (AoA) refers to the period within which a word, phrase, concept, or skill has been learned – typically, early AoA is categorised as before aged 6/7 years old, and late AoA reflects the period after aged 6/7 years old (Brysbaert et al., 2000; Ellis et al., 2010; Morrison & Ellis, 1995). The effect of early vs. late AoA has been shown across numerous experimental and language-related tasks (see Arnon et al., 2017; Brysbaert et al., 2000; Ellis et al., 2010; Stadthagen-Gonzalez et al., 2004). However, presently, it is uncertain as to whether or not AoA has been considered in previous studies; if it has not been considered, the potential influence of this omission is unknown. Moreover, it is unclear as to whether or not the hand-related effects that have typified many embodied language studies would persist in experiments where AoA was controlled.

In EEG research, the N400 event-related potential (ERP) component relates to a cluster of brain activity that is elicited when congruent/incongruent stimuli are processed (Kappenman et al., 2021) – a smaller N400 being associated with processing stimuli that are semantically related in a classical sense (e.g., *bread, butter*). However, the extent, if any, to which this applies to motor-related word pairings (e.g., *bowl, nest*) has yet to be explored; establishing more about this phenomenon could enhance embodied language theories. Specifically, hand-related pairings eliciting a reduced N400 would imply that the brain groups motor-related stimuli (i.e., that which is graspable) in a similar manner to stimuli related in a classical semantic sense. This would further suggest that processing words describing different types of objects is related to the objects` graspable features – a proposition that is at the heart of many embodied language theories (see Buccino et al., 2005, 2018; Gough et al., 2012; Marino et al., 2011;2014).

1.6 Thesis aims

The general aim of the current thesis was to further test theories of language embodiment and to explore some of the factors that could be influencing motor-related language findings. The current chapter aimed to provide an overview and background to embodied language theories, while Chapter 2 aimed to discuss the various methods and software programs that were used throughout the thesis. Chapter 3 tested how the potential embodiment of a lesser studied word category (adjectives – i.e., *hot*) affected subsequent motor responses to noun types (e.g., *iron*). Moreover, adjective/noun embodiment in Chapter 3 was examined using tasks requiring differing levels of processing, which allowed us to test whether or not effects, if any, were influenced by task demands. Chapter 4 tested the potential impact of *age of acquisition* (AoA) on previous studies that are in line with language embodiment. Thereafter, Chapter 5 examined the impact of AoA more directly to establish whether or not effects that are typically associated with embodiment would manifest in experiments when AoA was controlled. Chapter 6 aimed to measure the degree to which processing motor-related word pairings (e.g., *bowl, nest*) elicited a reduced N400 event related potential (ERP) component relative to unrelated stimuli (e.g., *bowl, lake*).

Chapter 2

General Methods

Overview

Throughout this thesis, many different research methods and experimental tools were employed. The aim of the current chapter is to review these methods and tools and to describe the different techniques that were used for each experiment. Generally, the thesis can be categorised via behavioural measures and electrophysiological measures. Additionally, many behavioural experiments required different types of tasks, and some research was conducted in person while some was conducted online.

The chapter begins with Section 2.1, which provides an overview of the different behavioural measures that were used throughout the thesis. Section 2.2 describes the electrophysiological measures and hardware employed. Next, Section 2.3 outlines the various software programs that were utilised, while Section 2.4 discusses some of the pros and cons of conducting research online. Section 2.5 provides an overview of the main statistical analysis techniques, and the chapter finishes with Section 2.6 – a synopsis on ethical considerations, participant recruitment, and some of the factors related to open science.

2.1 Behavioural measures

According to Lo and Andrews (2015), reaction time (RT) experiments provide researchers with a non-invasive way to examine behaviour. Typically, the speed of an RT is said to reflect the length of time taken to process a stimulus or perform a task while also reflecting the efficiency of the accompanying mental processes (Draheim et al., 2019). Traditionally, in experimental analysis, the mean RT from one experimental condition is compared to another, and this allows researchers to measure the effect of a given variable on processing and behaviour (Draheim et al., 2019). Accordingly, in relation to language processing, RTs offer a means to measure the speed at which a participant can process and respond to different categories of words. As discussed in Chapter 1, behavioural measures such as RT have been extensively used by researchers to examine the effect of motor-related and non-motor related language on motor behaviour (and vice versa). This has offered a viable addition to measuring the processing of sensorimotor language via neuroimaging and brain stimulation means only.

2.1.1 GoSignal task

In essence, a *GoSignal task* is a simple reaction time task that presents an onscreen stimulus that acts as a cue or signal for a participant to respond. Often, participants respond motorically (i.e., pressing a key on a computer keyboard), and accuracy and/or RTs to the signal are the usual outcome measures. Though simple, these types of tasks can be beneficial in examining a range of complex cognitive and behavioural processes. For example, a study by Van Den Berg and Neely (2006) used a simple reaction time task to examine the effect of sleep deprivation on participant performance. The study found that those who were sleep deprived took significantly longer to respond and made more errors overall. Later, Jaydari Fard et al. (2019) successfully used a similar task to demonstrate that athletes were less impacted by mental fatigue than non-athletes.

One of the defining features of a GoSignal task is that it does not require participants to make decisions about, or to categorise, stimuli that precede the response cue. This is potentially advantageous – in a language task where words precede the response cue – as although participants are required to read preceding words, it eliminates the added mental demands that accompany having to make decisions about words (Moseley & Pulvermüller, 2014). Accordingly, one could suggest that a GoSignal task allows for the examination of automatic or *bottom-up* processing. As one of the aims of the current thesis was to test the impact of shallow and deeper levels of processing on embodiment (see Chapter 3), a GoSignal task was a perfect fit to examine the former. Specifically, it allowed us to test behavioural responses to stimuli using a task that required processing at a shallow level.

2.1.2 Lexical decision task (LDT)

A *lexical decision task* (LDT) requires a participant to decide whether a string of presented letters is a real word (e.g., *cup*) or a non-word (e.g., *fligy*) (Libben, 2008; Perea et al., 2002). Thus, a LDT differs to a GoSignal task in that it *does* require a judgement or a decision to be made about presented stimuli. In a typical LDT, the participant decides by quickly pressing a button on a computer keyboard, and accuracy and RTs to the letter strings are the usual outcome variables (Marx & Ko, 2012; Meyer & Schvaneveldt, 1971). LDTs can also be presented in slightly different forms, with one such version utilising a yes/no paradigm. Here, the participant is required to read the letter strings and respond *yes* for a real word and *no* for a non-word (via allocated keyboard keys) (Gilchrist & Allen, 2015). The RTs acquired from this type of paradigm can be a very useful measure of the effect of different types of experimental manipulation, and LDT responses can also be used as an indirect measure of cortical motor activity. For instance, a study by Willems et al. (2011) used a yes/no LDT, alongside theta burst transcranial magnetic stimulation (TMS), to show that stimulating the hand area of left premotor cortex facilitated quicker right-handed RTs to manual verbs but not to non-manual verbs.

LDTs can also be presented in a slightly different format, whereby the participant is only required to respond to a real word and refrain from responding to a pseudoword. In this type of task, RTs to real words are generally of most interest – the theory being that the speed of response to real words reflects the cognitive accessibility of the presented word (Libben, 2008). Additionally, though not explicitly required for the task, distinguishing a word from a pseudoword has been reported to tap into certain elements of semantics (see Dreyer et al., 2015; Neininger & Pulvermüller, 2003) – thus making the level of processing slightly deeper than in a GoSignal task. For this reason, an LDT was one of the experiments used in Chapter 3 in the current thesis, as it allowed us to test the impact of a medium level of processing on motor response to language. LDTs were also used for our two *age of acquisition* (AoA) experiments (see Chapter 5), as the task has been reliably used in previous AoA tasks (see Arnon et al., 2017; Brysbaert et al., 2000; Ellis et al., 2010; Morrison & Ellis, 2000). All LDTs in the current project followed the go/no-go format, where participants had to respond to a real word and refrain from responding to a pseudoword.

2.1.3 Semantic decision task (SDT)

A *semantic decision task* (SDT) requires a participant to make an explicit judgement about the semantic features of a presented stimulus. This can include responding only when a word is concrete (see Marino et al., 2011) or deciding which of two presented words (e.g., *jog, sneak*) is most similar to a target word (e.g., *run*) (see Kemmerer et al., 2008). Other SDTs have required participants to respond only when a presented word or picture is a real object (e.g., Buccino et al., 2018) or to categorise nouns via their colour and related body part (Van Dam et al., 2012). Common to all SDTs is that participants are required to categorise stimuli based upon semantic properties.

As stated, one of the aims of Chapter 3 was to test the impact of differing levels of processing on motor responses to language. The GoSignal task (Experiment 3.1) and the LDT (Experiment 3.2) allowed us to examine the influence of shallow and slightly deeper levels of processing, respectively – however, neither task explicitly required participants to categorise stimuli based upon their semantic features. As an SDT does, it allowed us to assess a deeper level of processing than was afforded by the GoSignal task and LDT; consequently, a SDT was used for Experiment 3.3.

2.2 Electroencephalography

2.2.1 Overview

An electroencephalogram (EEG) is a tool that is used to measure electrical activity in the brain (Blinowska & Durka, 2006: Luck, 2014; Olejniczak, 2006). Typically, the EEG records brain activity non-invasively via electrodes that are attached to a scalp cap – often while a participant undergoes an experimental task (Jackson & Bolger, 2014). According to Srinivasan and Nunez (2012), scalp electrodes can record electrical currents of between 30-500 million cortical neurons, allowing for the observation of large-scale activity. EEG records these neurons by detecting the flow of electrical current in multiple cortical pyramidal cells that results from the summation of inhibitory and excitatory post synaptic potentials (PSPs) (Jackson & Bolger, 2014; Kappenman et al., 2021). This brain activity results in a region of positive charge on one side of the scalp and negative charge on the other – otherwise known as a *dipole* (Jackson & Bolger, 2014). The sum of dipole activity is then conducted to the scalp and recorded by nearby electrodes, and the positive or negative sequence at each electrode reflects a given wave of brain activity relative to a presented stimulus or task (Blinowska & Durka, 2006). Occasionally, EEG is used to record activity intracranially (i.e., directly from electrodes on the cortex) – such as with epilepsy patients undergoing surgery – though this method is quite invasive and thus limited (Srinivasan & Nunez, 2012).

One of the defining features of EEG is that it can provide a temporally accurate measure of the brain`s response to an event (Light et al., 2010). This can be achieved through the use and analysis of an event related potential (ERP) design. Here, the participant takes part in a number of trials, which are typically time-locked to the onset of stimuli, and neural activity during the trials is averaged to produce a precise brain response to the event (i.e., an ERP) (Britton et al., 2016; Kappenman et al., 2021). Occasionally, experimenters time lock to the response rather than to the stimulus onset, but time locking to the stimulus onset is often the preferred method (Luck, 2014; Kappenman et al., 2021). Both methods allow for an analysis of the brain`s electrical activity during an event of interest.

According to Sur and Sinha (2009), ERP components can be classified via those that are early and those that are later. Early components refer to those that peak within approximately 100 milliseconds post stimulus presentation and are thought to reflect sensory processing (Sur & Sinha, 2009). Contrastingly, later generated ERPs relate to the periods within which the stimulus is evaluated and are said to reflect information processing (Light et al., 2010). Notably, ERP waveforms/components are categorised via direction and timing. For instance, the P50 ERP component is a positive going waveform that peaks approximately 50 ms after stimulus presentation (Sur & Sinha, 2009). As suggested, the P50 ERP is reported to relate to sensory features of a stimulus as opposed to stimulus processing, though analysis of this component during certain conditions has been suggested to be a useful marker of early onset Alzheimer`s disease (Green et al., 2015). The N170 component relates to a negative going component that peaks at approximately 170 ms after stimulus onset; this component is said to be most active during face processing (Kappenman et al., 2021).

Of most interest to the current thesis is the N400. Specifically, the N400 is a negatively charged ERP component that peaks approximately 400 ms post stimulus and is purported to represent semantic congruency/incongruency. Typically, N400 amplitude has been found to be larger when incongruent or mismatched stimuli are presented and smaller when congruent stimuli are processed (Junge et al., 2021). The N400 was first discovered in a classic experiment by Kutas and Hillyard (1980). In the experiment, the authors reported a negative going brain wave, that occurred between approximately 250-600 ms after stimulus presentation, which appeared to result from *semantic deviation*. Explicitly, Kutas and Hillyard (1980) presented 7-word sentences – some of which ended with a moderately incongruent word (e.g., *he took a sip from the waterfall*) or a strongly incongruent word (e.g., *he took a sip from* *the transmitter*); neural activity was recorded from Cz, Fz, and Pz electrodes (i.e., central, frontal, and parietal sites, respectively). An analysis of brain activity as participants processed the final word in each sentence showed significantly greater N400 amplitude during the strongly incongruent condition vs. the moderately incongruent conditions. The authors postulated that N400 activity must be related to a disruption to expectations during processing, or *semantic incongruency*. Since then, the N400 is estimated to have been examined in over 1000 studies – making it a particularly important outcome variable in language research (Al-Azary et al., 2022; Beres, 2017). As the component is thought to reflect congruency/incongruency, examining the N400 was an ideal fit for our final experiment (see Chapter 6). Explicitly, it allowed us to test the degree to which motor-related word pairings influence a brain wave that has been traditionally associated with semantic processing in a classical sense.

2.2.2 Pros and cons of EEG research

Overall, there are many potential advantages to using EEG – such as the method of recording brain activity itself. For example, as stated, EEG is generally non-invasive, as electrodes are recorded from the scalp and not from inside the brain. This feature allows for the examination of neural activity without having to record directly from the brain – making EEG quite practical and comfortable for participants (Zion-Golumbic, 2007). EEG is also very safe for participants who may have bodily implants or metal, whereas functional Magnetic Resonance Imaging (fMRI) can pose serious safety risks to these individuals (Stemmer & Connolly, 2011). Additionally, in contrast to fMRI, EEG is less likely to induce claustrophobia, and it does not require the positioning of participants in a particular way (Stemmer & Connolly, 2011). From a research perspective, EEG and its associated equipment is reasonably inexpensive to use and quite simple to operate, with training (Zion-Golumbic, 2007). EEG is also advantageous, as it allows researchers to detect and remove motor artifacts, which eliminates the possibility of having to exclude data (Beres, 2017). However, arguably, the most beneficial feature of EEG is that it allows researchers to track neural activity across time. Contrastingly, tools like fMRI or Positron Emission Tomography (PET) – which measure regional cerebral blood flow – offer poor temporal resolution, as blood flow takes time to change from one area to the other (Luck, 2014). Accordingly, EEG is much more suitable to recording precise time measurements of brain activity (Harrison & Connolly, 2013). However, as they record local cerebral blood flow, PET and fMRI offer more suitable measures of spatial resolution, whereas the distance of electrodes makes it quite complex to accurately measure spatial resolution using EEG (Hennig et al., 2003; Luck, 2014). All in all, though, the ability to produce high-resolution temporal data and the ease at which EEG can be administered and recorded make it a beneficial research tool.

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2.2.3 EEG hardware and setup

In the current thesis, the EEG signal was recorded using a Biosemi ActiveTwo system with a 32-electrode cap and a 10-20 international system layout (see Figure 2.1). Thirty-two active sintered Ag-AgCl electrodes were used. According to some research groups (e.g., Laszlo et al., 2014), this electrode material amplifies EEG at the scalp ensuring that there is minimal interference from external noise. Additionally, wet electrodes are considered more comfortable for participants compared to dry electrodes (Saab et al., 2011), and they are thought to further reduce noise from external sources (Mathewson et al., 2016). The EEG cap fitting took place in a preparation area just outside the Maynooth University (MU) testing cubicles. Six electrooculogram (EOG) electrodes were fixed, via electrolyte gel and sticky tape, to the participant`s face. Four of these were positioned slightly above and below the right eye and at the corner of the right and left eye. Two further mastoid electrodes were placed behind the participant`s right and left ear (see Figure 2.2). A head measurement was then taken for each participant, before a suitable 32-electrode EEG cap was fixed onto their head. The cap was secured via a Velcro strap that was positioned under the chin. Anatomically, the cap was positioned so as to allow central electrode locations to be vertically aligned between the nasion and inion (see Figure 2.3). Electrolyte gel was then used to fill the 32 electrode sites on the EEG cap. The 32 electrodes were then attached to the corresponding location on the cap, and the participant was taken to the Faraday cage – just beside the preparation area.

Inside the Faraday cage, the scalp ribbon and EOG cables were connected to an AD-box. The AD-box digitised sensor signals at a 24-bit sampling resolution; digital outputs were then sent to a receiver by an optical fibre cable. Manually written EEG triggers from the *EPrime* software program were obtained by the receiver, and trigger outputs were sent to the computer that was running the BioSemi ActiView acquisition program (see Figure 2.4 for a layout of the setup). When the hardware setup was completed, direct current offset for each electrode was examined on a monitor in the adjacent control room. Extra gel was applied to problematic electrode sites, where applicable.

During testing, ERP data were recorded using a battery-powered amplifier in a room containing a Faraday cage – the purpose of which was to reduce the impact of electrical mains noise on the signal. Data were then relayed to a computer in a nearby control room. EEG signals were recorded on a Dell machine with a Windows 10 operating system. A separate Dell machine with a Windows 10 operating system was used to administer the N400 trials to the participant in the Faraday cage. Only the computer monitor was present within the cage; the computer hard drive was situated in the nearby control room. Raw EEG data for these participants were examined using Brainstorm, version 3.210 (Tadel et al., 2019). The data were sampled at 2048 Hz but were down sampled offline to 512 Hz (see Chapter 6).

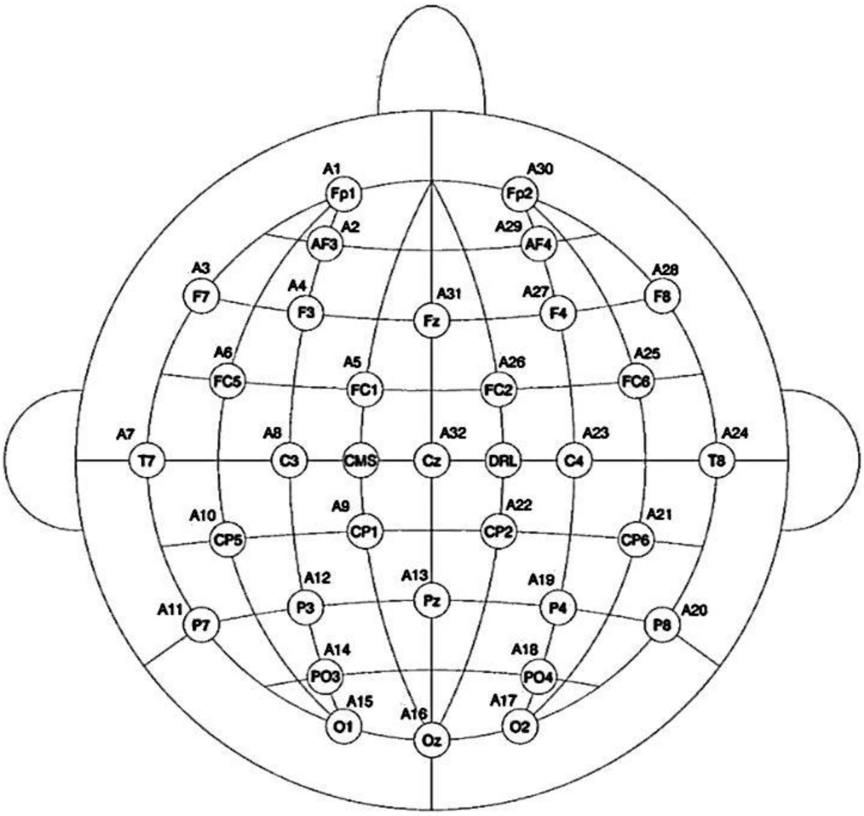


Figure 2.1. Layout of the BioSemi 32-electrode cap.

Image taken from BioSemi website (2022).

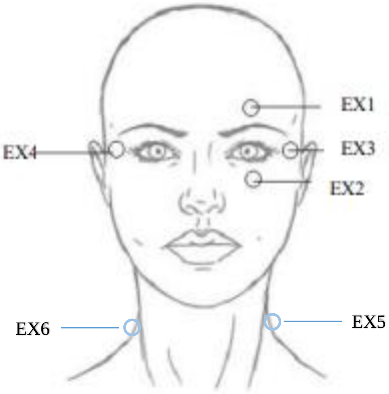


Figure 2.2. Positioning of EXG electrodes.

Figure 2.3. Measuring for the EEG cap.

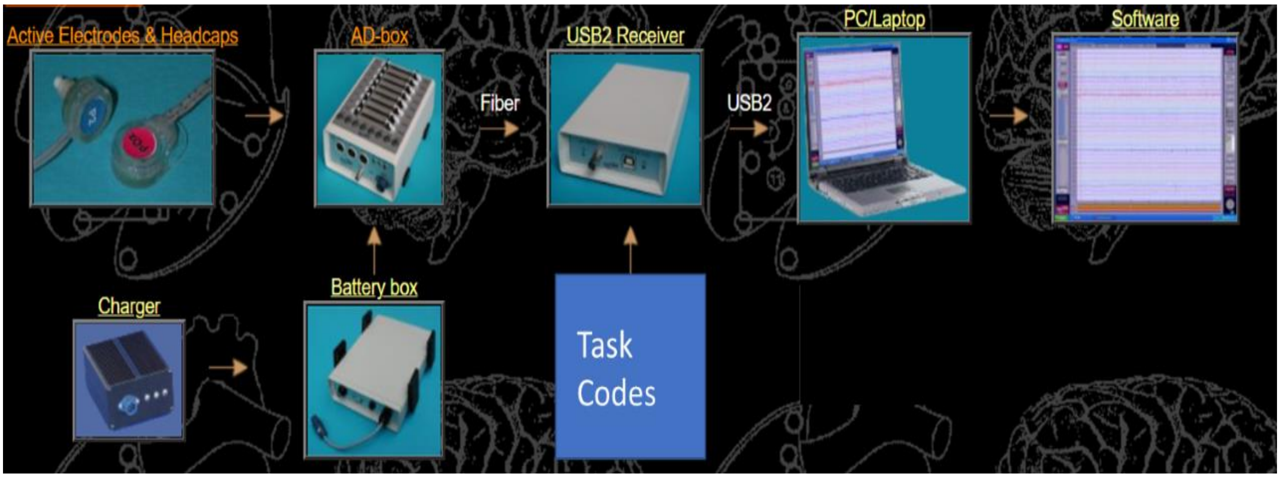


Figure 2.4. The Biosemi ActiveTwo System and associated hardware that were used to record EEG – adapted from BioSemi website (2022).

2.3 Software systems

2.3.1 EPrime

EPrime is a collection of inter-related software programs designed to allow researchers to construct and run computer-based behavioural experiments (Psychology Software Tools, 2022). *E-studio* is the *EPrime* subprogram where researchers can build different types of experiments using images, videos, text, and sound. Generally, experiments are built by dragging various E-Objects from a toolbox to an experimental timeline (see Figure 2.5). However, more complex experiments usually require researchers to add some basic code via an inline object (Psychology Software Tools, 2022). Through these processes, researchers can manipulate the established number of stimuli, trials, and blocks to be used in their experiment. The *E-Run* subprogram is then used to run the experiment, and from here, experimental data are sent to a EDAT file (Richard & Charbonneau, 2009). Relevant data can be extracted from the EDAT file and analysed as per the experimental requirements.

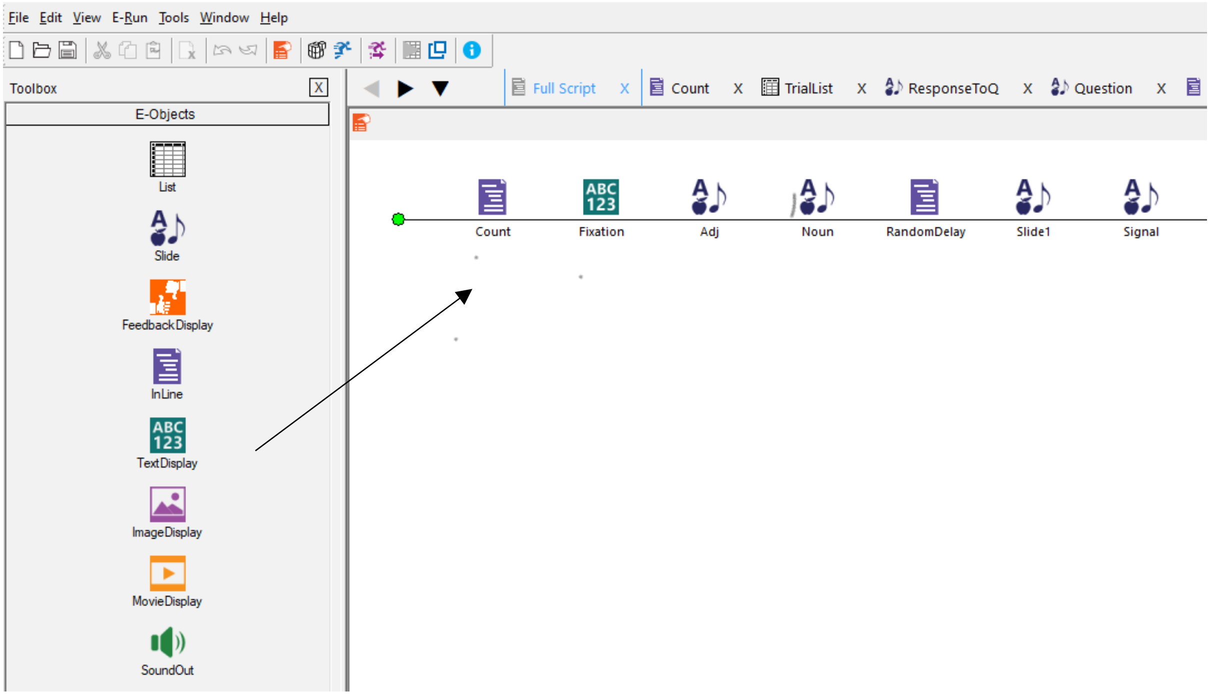


Figure 2.5. Example of E-Objects (left) and EPrime experimental timeline (right).

According to Kim et al. (2019), *EPrime* software is quite easy to use and to run and is thus regularly used in university settings. *EPrime* software has also been successfully used in psycholinguistic research (see Su & Liu, 2020), and the skills learned in programming *EPrime* are said to be easily adapted to many other computer programmes (Spapé et al., 2020). In the current project, all in-person behavioural tasks were constructed using the *EPrime* software programs (versions 2.0 and version 3.0 – see individual experimental chapters). *EPrime* was also used to build and run the ERP experiment and its accompanying behavioural task. However, as *EPrime* could not be run online (at the time of early Covid-19 restrictions in Ireland), a suitable software program had to be learned and used.

2.3.2 PsychoPy

A software system called *Psychopy* was used to construct the behavioural tasks that were conducted online. Similar to *EPrime*, PsychoPy is a programming system that allows researchers to build experiments using a range of text, images, videos, and sound (Peirce et al., 2019; Seitz et al., 2021) – via an experimental builder (see Figure 2.6). Further, if preferred, researchers can design and write their PsychoPy experiments using Python or can simply add pieces of code to the experimental builder – as shown in Figure 2.7 – allowing PsychoPy to present a large variety of stimuli (Seitz et al., 2021). PsychoPy is also quite easy to use, as it was specifically designed to be accessible to students and to be flexible for researchers (Peirce et al., 2019). However, most applicable to the current project was that PsychoPy version 3.0 could be transferred online to run with participants.

To run online, PsychoPy experiments can be sent to a platform called *Pavlovia* (https://pavlovia.org/). Specifically, Pavlovia is a site where online experiments can be stored and run, and data from associated experiments can be held securely (Peirce et al., 2019). Further, Pavlovia experiments can run from most browsers (though Chrome and Firefox are recommended) – making the system incredibly accessible for participants (Peirce et al., 2019). Pavlovia has successfully hosted studies on psychophysics (e.g., Zhao et al., 2022), masked priming (e.g., Angele et al., 2022), and even animal cognition (e.g., Seitz et al., 2021). The accessible PsychoPy builder and the reliable Pavlovia hosting system were an ideal fit for our online experiments.

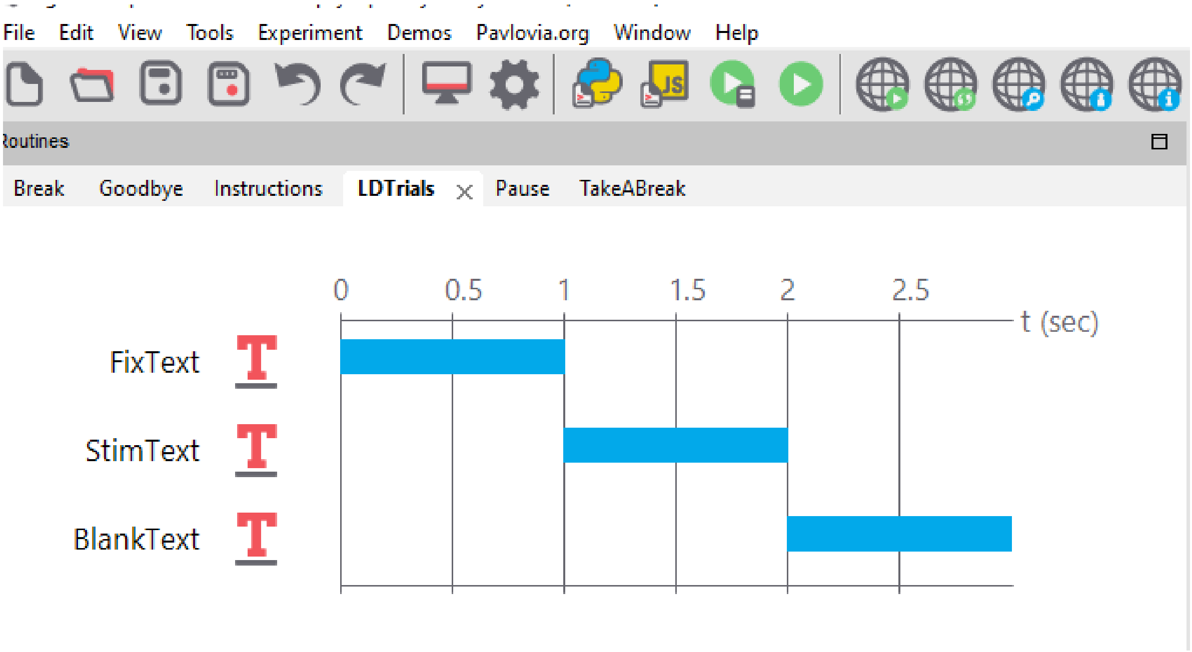
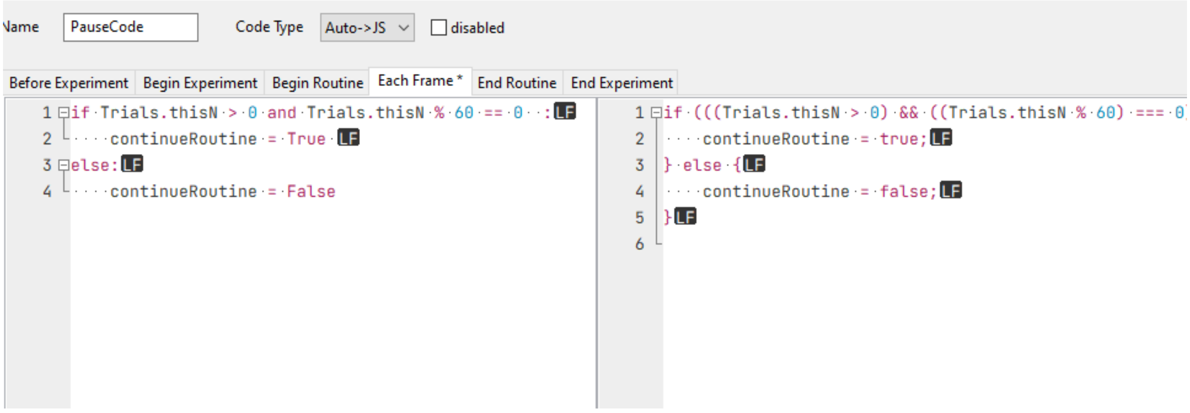


Figure 2.6. Example of the PsychoPy experimental builder


Name PauseCode
Code Type Auto->JS
☐ disabled

```
if Trials.thisN > 0 and Trials.thisN % 60 == 0  :
    continueRoutine = True 
else:
    continueRoutine = False
```

```
if (((Trials.thisN > 0) && ((Trials.thisN % 60) === 0
    continueRoutine = true;
} else {
    continueRoutine = false;
}
```

Figure 2.7. Example of a basic break code in PsychoPy.

2.4 Demographic measures

2.4.1 Qualtrics

Qualtrics ^{XM} is a software system that allows researchers to build and present research surveys (Qualtrics, 2022). Typically, surveys on Qualtrics are constructed and modified via a builder – a feature which enables users to create surveys using different question types and graphics (Molnar., 2019). For example, in relation to question types, researchers can choose one of many options including *multiple choice, text/graphic*, or a simple *text entry* (see Figure 2.8). Further, researchers can modify the content type for each question by presenting *text*, a *graphic* or a *file* (see Figure 2.9). In addition to these features, Qualtrics also enables researchers to design their questions so as participants must make a choice before the questionnaire moves on (Qualtrics, 2022). This is potentially useful, as it reduces the probability of missing data.

One of Qualtrics` many useful features is that it can bring users to the end of a survey or to a subsequent link. In the current thesis, this feature was relevant for Chapter 3 (the lexical decision task (LDT) online) and Chapter 5 (older adult LDT), as it allowed participants to move straight from the questionnaire to the relevant experiment by simply clicking on a link. For both experiments, Qualtrics was also used to document each participant`s age, gender, handedness, and first language as well as providing basic information about the experiment. For the older adult LDT, the Qualtrics form also documented whether or not any participant had motor-related issues (see Figure 2.10). All Qualtrics data were downloaded to an Excel file for analysis.

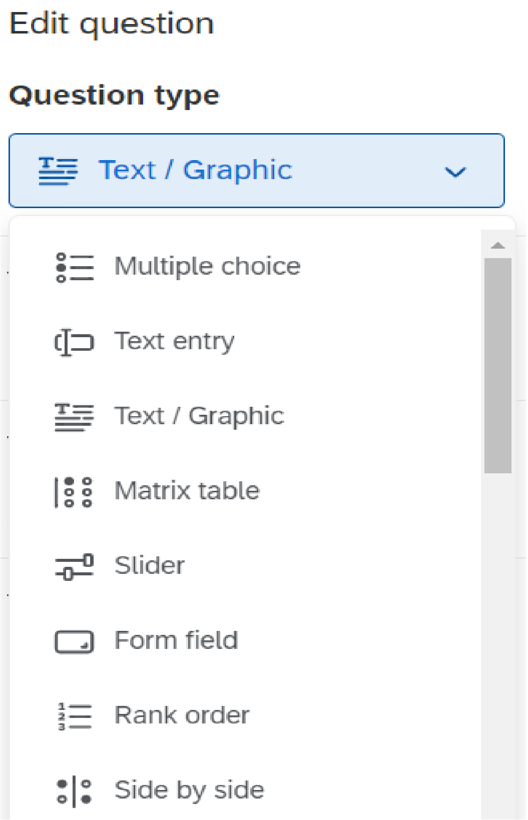


Figure 2.8. Qualtrics question types.

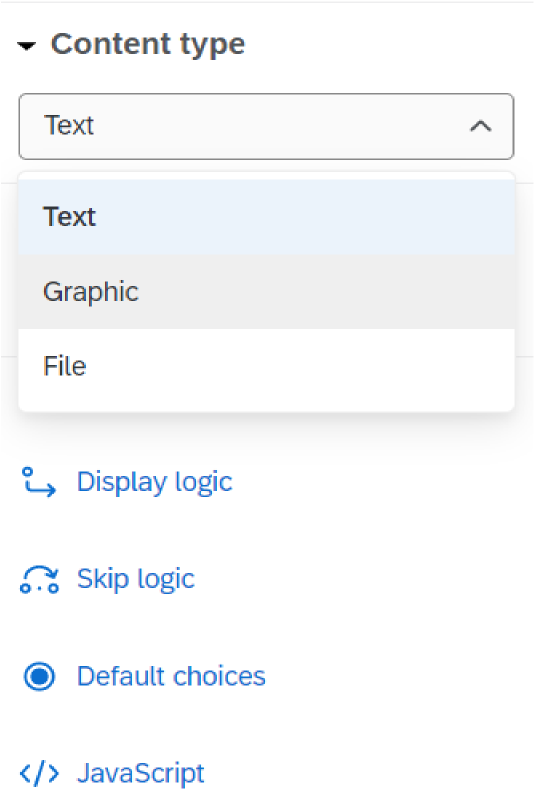
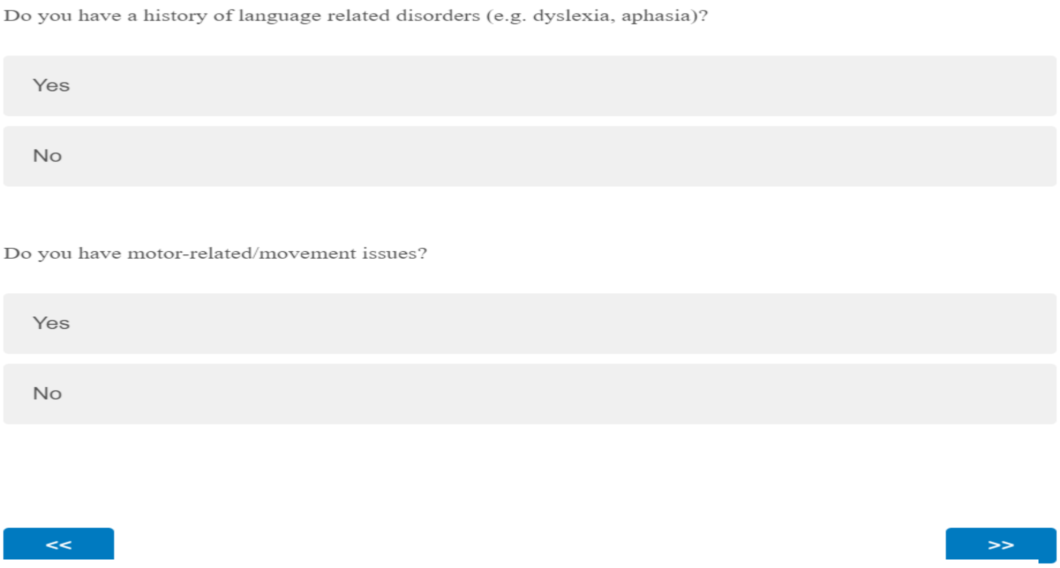


Figure 2.9. Qualtrics content types.


Do you have a history of language related disorders (e.g. dyslexia, aphasia)?

Yes

No

Do you have motor-related/movement issues?

Yes

No

Figure 2.10. Example of a Qualtrics question.

2.4.2 Edinburgh handedness inventory

The Edinburgh handedness inventory (see Appendix A) is a brief questionnaire designed to establish a participant's handedness (i.e., which hand they mostly use) (Oldfield, 1971). To establish handedness, a series of regular manual actions (e.g., writing) and objects (e.g., spoon) is presented, and the participant documents which hand they usually use to perform the action or to interact with the object described. If the participant`s preference is so strong that only one hand is ever used, they are instructed to place two crosses (++) in the corresponding left or right box (Oldfield, 1971); mostly using one hand requires one + in the corresponding box, and equal left and right use requires one + in each. After completion, the researcher scores the inventory by subtracting the left from the right scores, dividing the difference by the total number of plusses in both columns, and multiplying the balance by 100 (Edlin et al., 2015). A score of + 40 or more indicates that the participant is right-handed; a score of -40 suggests left-handedness (Caplan et al., 2010). Those who score in between are thought to be ambidextrous.

Oldfield (1971) proposed that a single handedness index would be particularly beneficial to researchers, as it would allow them to compare handedness data with others. Additionally, it provides researchers with an insight into the relationship between handedness and cerebral laterality (Edlin et al., 2015) – which is particularly relevant for the current thesis. For example, it has been proposed that language and handedness are related; in right-handers, both are typically controlled by the left hemisphere, whereas in left-handers, language is often right lateralized (Schmitz et al., 2017). Our research centres around testing the interaction between language processing and motor activity; thus, testing right-handers` responses during language processing provides the most reliable way to measure this – given that both are left lateralised. Essentially, the Edinburgh inventory allowed us to screen participants for handedness and to remove the potential confound of laterality. The inventory was also used to record participants` age and gender (self-reported).

2.5 In-person research vs. online research

Much of our research was conducted in person at the MU Department of Psychology`s testing cubicles. For example, we conducted 6 experiments in total (not including our *age of acquisition* (AoA) review and analysis – see Chapter 4), and four of these took place in person. However, due to Covid-19 restrictions and social distancing, the experiments we ran in 2020 and in much of 2021 had to be moved online. Specifically, in Ireland, from March-December 2020 and for various months in 2021, no face-to-face contact was allowed; thus, no in-person testing could take place. Accordingly, some of our research had to be run online. There are many potential advantages and disadvantages to running experiments online and many factors that warrant consideration; the issues most applicable to our work will be discussed in the next section.

Arguably, the greatest potential concern with conducting research online relates to the lack of experimental control and the subsequent quality of data recorded. For instance, typically, when a participant comes to the MU laboratory, the experimenter has standardised the screen distance/size and the environmental lighting, and the cubicles are located in a quiet space with minimal distractions. However, when a participant partakes in an experiment outside of the lab, factors such as screen distance/size, lighting, and noise levels are potentially more variable. Additionally, the fact that participants are not being observed by experimenters may result in lack of attention and/or motivation, and there may be device variability – all of which present potential issues regarding the quality of data collected (Sauter et al., 2020). Internet stability can also be an issue, and this could potentially result in unreliable RTs (Sauter et al., 2020).

However, arguably, many of the abovementioned issues can be avoided through appropriate experimental design. For example, as highlighted, running PsychoPy experiments on Pavlovia does not depend upon an internet connection – thus removing the potential for unreliable RTs due to internet-related issues. Further, PsychoPy has been found to be extremely precise in measuring RTs online, particularly when using experiments that require responses across multiple conditions (i.e., a lexical decision task or an implicit association test – Bridges et al., 2020). Kim et al. (2019) also suggested that not having a researcher present during testing may actually enhance ecological validity through reduced social desirability bias and reduced cognitive load.

In addition, using online participants can provide researchers with access to greater numbers of participants. Moreover, participants that are recruited online tend not to be solely comprised of university students – potentially allowing for a more reflective sample (Grootswagers, 2020). Taken together, testing participants online can offer many advantages to researchers, and it offered us a viable alternative to in-person testing when no such participation was allowed. Interestingly, both experiments that we ran online (Experiment 3.3 and Experiment 5.2) utilised a task with multiple conditions (an LDT) that was written on PsychoPy and hosted via Pavlovia. In both experiments, our analysis of missed responses and false positives also provided an accurate measure of attention levels. Further, all analyses were within-groups, so any potential differences in screen position or size were not applicable. All in all, our LDTs were quite easily transferable to online audiences, and our methods ensured that data were not compromised.

2.6 Statistical analyses

All data were analysed using Microsoft Excel (version 16.0), IBM`s Statistical Package for the Social Sciences (SPSS, version 28), and Brainstorm (version 3.210 – Tadel et al., 2019). Generally, Excel was used to compute means and standard deviations for each participant for each experimental condition. These data were then checked for individual and group outliers – as per our pre-experimental threshold of 85 % (specifics of this analysis relative to each experiment is documented in each experimental chapter). Data were then transferred to SPSS for statistical analyses. EEG data were first processed in Brainstorm before being transferred to SPSS. All experiments utilised a repeated-measures design, and all factors of interest were subjected to an analysis of variance (ANOVA). *Post hoc* tests were employed, where required, and Bonferroni corrections were also used, if necessary. In all experiments, $p < 0.05$ was taken as statistical significance – as per the standard in psychological research.

2.7 Ethical considerations, participant recruitment, and open science

All research was conducted in accordance with the American Psychological Association`s (APA) and the Psychological Society of Ireland`s (PSI) codes of conduct. Further, each experiment was reviewed and passed by a research ethics board at MU. Each chapter provides the relevant detail. Generally, in-person participants were sourced from MU and surrounding areas and from the Greater Dublin area. Additionally, some in-person participants were sourced from a research participation pool in MU`s Department of Psychology – these participants were given course credit for their time. Those who participated online were also sourced from the psychology participant pool and from the online forums *Reddit* and *LinkedIn* (see details within).

All participants in all experiments were over the age of 18 years, and all consented to take part. Those who participated in person provided their consent manually after being given a brief overview of the task requirements. These participants were also informed that they could withdraw at any time during the experiment, with no consequences, but they could not withdraw their data after the experiment as it would be logged into the system. In-person participants were also fully debriefed thereafter and were provided with researchers` contact detail should any issues arise afterwards. The online participants provided consent electronically, via a Qualtrics form, that also provided a brief overview of the task requirements. These participants were also given the researchers` contact details should any issues arise afterwards.

The research conducted for this thesis also tried to follow some of the principles of *open science*. Specifically, open science refers to a movement which essentially aims to improve research practices and data transparency (van der Zee & Reich, 2018). According to the American Psychological Association (APA, 2022) the movement developed out of the frustrations that arose from the replication crisis – some of which were due to substandard research practices. Accordingly, open science encourages a standardised set of practices which seek to enhance the integrity and generalisability of research (Hagger, 2022).

One of the practices that the open science movement encourages relates to *open design* and *pre-registration*. Generally, through the practice of open design, researchers are encouraged to provide an accurate account of their study design and to highlight any changes that may have taken place during the process (Crüwell et al., 2018). One of the ways that this can be facilitated is through the practice of pre-registering designs, hypotheses, and planned analysis before the study begins (Spellman et al., 2017). This should allow a study to be more transparent and should greatly reduce the possibility of bias while increasing the probability of replication. Studies can be pre-registered on many different databases – some of the recommended ones are *Open Science Framework* (www.osf.io), *AsPredicted* (https://aspredicted.org), and *Registered Reports* (www.cos.io/rr).

In the current thesis, the design and planned analyses for the EEG experiment and accompanying behavioural experiment (see Chapter 6) were pre-registered on *AsPredicted* before the study began (https://aspredicted.org/see_one.php). Additionally, separately, all stimuli that were used in each experiment are provided in the appendices. The precise comparisons that were performed with the studies reviewed for Chapter 4 have also been provided in the appendices.

Chapter 3

The Embodiment of Adjectives

Abstract

Theories of language embodiment typically propose that language and action are interrelated (see Gallese, 2008; Marino et al., 2011). However, much of our knowledge on embodiment has been derived from studies that have tested motor activity and/or motor responses during the processing of verbs and nouns only. The current experiments tested the embodiment of *adjectives* – thus adding a much lesser studied word category to existing embodiment research; we also tested the impact of differing levels of processing on motor responses. In the current chapter, three behavioural experiments were conducted – a GoSignal task (*N* = 40), a lexical decision task (online) (*N* = 130), and a semantic decision task (*N* = 40). Each tested the effect of Adjective type (negative vs. non-negative vs. pseudo) on the potential affordance effect of Noun type (i.e., different reaction times to hand-related vs. non-hand related nouns). The various tasks also afforded the opportunity to examine different levels of processing. The GoSignal task showed significantly quicker hand responses to hand-related nouns but no modification via Adjective type. The lexical decision task and the semantic decision task found significantly slower responses for hand-related nouns but significantly quicker hand responses during trials with negative and non-negative adjectives only. Thus, task demands impacted processing of motor-related language; issues such as priming and other potential influencing factors are discussed within.

3.1 Introduction

Traditional language models proposed that processing words relies upon symbolic mental representations, as language and physical reality are separate phenomena (see Bedny & Caramazza, 2011; Fodor & Pylyshyn, 1988). Theories of *language embodiment* contrast with this view and propose that language is rooted in sensory and motor experiences (Barsalou, 1999; Buccino et al., 2018; Gallese, 2008; Glenberg & Gallese, 2012; Marino et al., 2011; Pulvermüller, 2005; Zarr et al., 2013). Evidence for embodiment theories has come from behavioural experiments (e.g., Buccino et al., 2005; Marino et al., 2011), brain imaging studies (e.g., Hauk et al., 2004) and brain stimulation studies (e.g., Gough et al., 2013), which have suggested that processing language is related to experiences of the actions, objects, and events to which the language refers. For instance, Hauk et al. (2004) demonstrated in a functional magnetic resonance imaging (fMRI) experiment that reading words referring to hand actions (e.g., to *wash*) and foot actions (e.g., to *kick*) activated the somatotopically organised regions of premotor and primary motor cortex that are active during hand actions and foot actions, respectively. This implies that the cortical motor regions that underpin the production of specific bodily actions are also involved in processing language describing specific bodily actions, which suggests that motor activity and language processing are closely related.

Several behavioural experiments also offer support for this assertion, by demonstrating that processing verbs performed with specific body parts modulates response times (RTs) that are performed with the corresponding body part (see Buccino et al., 2005; Boulenger et al., 2006; Mirabella et al., 2012; Repetto et al., 2013; Andres et al., 2015; Gianelli et al., 2020). Some behavioural experiments have shown that processing action-related language can *interfere* with motor responses that are performed with the body part described in the language. For example, Buccino et al. (2005) found that participants' hand and foot RTs to the concreteness of auditorily presented sentences were significantly slower when performed during the processing of sentences containing hand actions (e.g., *he took*) and foot actions (e.g., *he kicked*), respectively. Similarly, Sato et al. (2008) found that participants` hand RTs were significantly slower during the processing of visually and auditorily presented hand-related verbs – relative to foot-related verbs and abstract verbs. The modulation of RTs in these experiments and others (see Fernandino et al., 2013; García-Marco et al., 2019) is said to occur, because the motor cortex is involved in both the processing of the bodily-specific verbs and the execution of the bodily responses – and hence the disruption when both are performed simultaneously (Sato et al., 2008).

There are also behavioural experiments which have shown that processing language referring to bodily actions can *prime* motor responses performed with the body part described in the actions – when the motor responses are performed at a certain timepoint *after* the language is presented. For example, Boulenger et al. (2006) found that participants` hand RTs towards a target were significantly quicker when performed approximately 550 ms after verbs referring to hand actions were presented. More recently, Klepp et al. (2017) showed that processing hand-related and foot-related verbs primed subsequent hand and foot motor responses, respectively, that were performed from 400 ms onwards after verb presentation. These facilitatory effects are said to result because the hand and foot cortical motor areas have become activated during the processing of the hand- and foot-related words, and the prior motor activation speeds up – or primes – the subsequent motor responses (Boulenger et al., 2006). Interestingly, Sato et al. (2008) found that processing hand-related verbs had no effect on hand RTs performed from 1150 ms onwards after word presentation – suggesting that processing bodily language will only prime a subsequent motor response up to a certain point. Thus, processing action words appears to be related to experiences of the actions to which the words refer and can either interfere with, or facilitate, motor responses performed with the corresponding body part – depending upon when the motor response is performed. This suggests that processing verbs describing bodily actions involves the same neural substrates that underpin the production of the bodily actions – and that language and motor experience are interlinking processes.

Language embodiment theories are further supported by experiments which have shown that processing nouns referring to objects upon which the body can act involves the regions of motor cortex that are activated during object interactions. For instance, a 2011 study by Marino et al. found that processing nouns referring to graspable/hand-related objects (e.g., *pencil*) inhibited hand RTs that were performed from 150 ms onwards after noun presentation. The same interference was not evident when hand responses were performed during the processing of foot-related nouns (e.g., *step*) and abstract nouns (e.g., *jealousy*) or when hand responses were performed at a much later point (1150 ms onwards) after word presentation (Marino et al., 2011). Zhang et al. (2016) later showed that processing pictures of hand-related objects and words referring to hand-related objects (e.g., *pen*) facilitated quicker subsequent hand RTs which were performed ~ 600 ms after word presentation. Their study also found that foot RTs were significantly quicker after words referring to foot-related objects and pictures of foot-related objects were processed (Zhang et al., 2016). These findings and other similar findings (see Marino et al., 2014; Buccino et al., 2018) are said to result, because the objects` features provide the motor system with the potential to act upon such objects. As with hand-related verbs, the motor activations can either inhibit a motor response that is performed early after word presentation (~ 150 ms) or facilitate a response that is performed at a later point after presentation (~ 400-1000 ms). This provides further support for the claim that language processing is an embodied process that is related to the motor experiences to which the language refers.

However, theories of language embodiment are not universally accepted, and there are many who suggest that the motor cortex does not play a functional role in language processing (see Mahon & Caramazza, 2005; de Zubicaray et al., 2013; Hickock, 2014). Additionally, much of the embodiment research has tested responses to verbs (e.g., Buccino et al., 2006; Sato et al., 2008) and nouns (e.g., Marino et al., 2011; Buccino et al., 2018) only, so current embodiment theories are generally based upon a limited set of word categories. There are other categories of word that could also be examined, as language embodiment predicts that all words related to sensorimotor experience are embodied – regardless of grammatical category (Marino et al., 2011). For instance, certain types of adjectives describe properties that are related to sensorimotor experience (e.g., *heavy, smooth*), so these types of adjectives could also be embodied. Only Gough et al. (2013) have tested this hypothesis directly and examined how processing single adjectives containing either negative properties related to avoidance (e.g., *slimy, broken*) or non-negative properties related to approach (e.g., *soft, graspable*) activated the primary motor cortex.

The experiment by Gough et al. (2013) applied single pulse transcranial magnetic stimulation (TMS) either to the left hemisphere primary motor regions that are involved in grasping or to the left primary motor regions involved in releasing actions, 150 ms after the adjectives were presented. Motor evoked potentials (MEPs) from the first dorsal interosseous (FDI) muscle that is involved in grasping actions in participants` right hands and from the extensor communis (EC) muscle of the right forearm that is involved in releasing actions, were then examined (Gough et al., 2013). The results showed a significant reduction in MEPs in the EC muscle of participants' right arms while adjectives related to avoidance were processed and a trend towards a significant reduction in the FDI hand muscle involved in grasping actions while adjectives related to grasping were processed. Gough et al. (2013) proposed that these findings resulted, because adjectives related to avoidance and approach are processed in the same neural areas that are involved in releasing actions and grasping actions, respectively. This supports the proposition that primary motor regions are also involved in processing adjectives with properties related to motor experience and suggests that adjectives are also embodied. The current experiment seeks to further test the embodiment of adjectives – but in a slightly different manner to the Gough et al. (2013) experiment.

As discussed, processing hand-related nouns can either inhibit or facilitate hand motor responses – depending upon task demands and the timing of the motor response. For example, hand RTs are typically slower when performed during the early stages of the processing of hand-related nouns (within approximately 150-200 ms), as the motor system is involved in both the processing of the language and the production of the motor response (Marino et al., 2011). However, participants` hand RTs are often quicker when performed at a later stage after language presentation (from approximately 400-1000 ms), as the motor system has already become activated during the processing of the word, and the prior motor activation facilitates – or speeds up – the subsequent motor response (Zhang et al., 2016). Either way, typically, processing hand-related nouns elicits different hand motor activity than processing non-hand related nouns. The present experiment tested whether or not this potential effect for hand-related nouns was modified by *Adjective type*. Specifically, it examined what happened when participants performed a hand response to a hand-related noun within a timeframe that tends to facilitate a motor response (approximately 500-700 ms onwards), but the nouns were preceded by different types of adjectives – some of which should inhibit a motor response. In essence, it tested if Adjective type modified the different effect that hand-related nouns tend to have over non-hand related nouns.

This was achieved by presenting participants with hand-related nouns (e.g., *plate*) and non-hand related nouns (e.g., *event*) that were preceded by negative adjectives in one condition (e.g., *smashed plate, shocking event*), non-negative/positive adjectives in another condition (e.g., *plastic plate, special event*), and pseudo adjectives in another condition (*mry plate, leengwtg event*). Participants were required to perform a hand response as quickly as possible to a GoSignal that followed each noun presentation, and the experiment expected a significant main effect for hand-related nouns overall (i.e., quicker RTs). However, our main focus was on trials where hand-related nouns were preceded by negative adjectives – thus, the interaction effect between Noun type and Adjective type was of particular interest. During these conditions, according to some embodiment theories (e.g., Gough et al., 2013; Glenberg & Kaschak, 2002). the negative adjectives should prime the hand area of motor cortex to retract from stimuli, thereby inhibiting the subsequent effect of processing the hand-related noun. The non-negative adjectives and pseudo adjectives were not expected to inhibit the effect of hand-related nouns and hence the predicted difference in RTs during these conditions.

The experiment also tested the influence of masking on language embodiment; thus, the adjective/noun stimuli were presented in two different conditions – one where the adjectives were fully visible onscreen and one where the adjectives were masked. Previous behavioural experiments have shown that the properties of briefly presented masked stimuli are unconsciously processed (see Dehaene et al., 1998), and this unconscious processing can influence subsequent RTs. The present experiment explored this phenomenon in relation to language embodiment by testing if the inhibitory properties of the briefly masked adjectives were applied to the subsequently presented nouns.

GoSignal experiment

3.1.1 GoSignal Method

3.1.1.1 Participants

A total of 44 native English speakers (22 females and 22 males – according to self-reports) took part in the experiment – all were aged between 18 and 48 years (*M* = 28.7, *SD* = 9.3). These participants were primarily recruited via poster advertisement that was displayed in various locations throughout Maynooth University (MU) and from the experimenter`s contacts. All were required to complete an Edinburgh Handedness Inventory Form (Oldfield, 1971) to establish their handedness. One participant`s score on the form was inconsistent with their behaviour, so their data were removed before the final analyses. The remaining 43 participants scored an average of 84.7 (*SD* = 15.2) and were thus mostly right-handed (-100 = totally left-handed, 0 = neutral, + 100 = totally right-handed; Oldfield, 1971). Three more participants` data were later removed due to too many errors (see statistical analyses section). None of the remaining participants reported issues with psychological/neurological impairment; history of epilepsy or memory issues; or history of language related disorders (e.g., dyslexia, aphasia). No incentives were offered for participation. The experiment was approved by MU`s Social Research Ethics Sub-Committee (SRESC-2018-144).

3.1.1.2 Stimuli

The stimuli were 120 different combinations of adjective and noun (see Appendix B). These were comprised of 20 hand-related nouns combined with 20 negative adjectives (e.g., *smashed plate*), 20 non-negative adjectives (e.g., *plastic plate*), and 20 pseudo adjectives (e.g., *mry plate*). Additionally, 20 non-hand related nouns were combined with 20 separate negative adjectives (e.g., *shocking event*), 20 separate non-negative adjectives (e.g., *special event*), and 20 separate pseudo adjectives (e.g., *leengwtg event*). Whether or not stimuli were hand-/non-hand related or negative/positive was agreed upon by the three researchers involved in the thesis. Moreover, to ensure consistency, we statistically compared our word categories for written frequency, verbal frequency, number of syllables, and imageability – via the MRC database (Coltheart, 1981). Written frequency was examined across the two most commonly used measures – Kucera-Francis (1967) and Thorndike-Lorge (1944) written frequency. In terms of Kucera-Francis, there was no significant main effect of word category (F (3,111) = 2.44, p = 0.07) – hand-related nouns (M = 35.2, SD = 27.5) vs. non-hand related nouns (M = 101.6, SD = 147.7) vs. negative adjectives (M = 64.1, SD = 108.5) vs. non-negative adjectives (M = 84.1, SD = 154.2) and no significant main effect of Adjective type (i.e., negative vs. non-negative) (F (1, 72) = 2.93, p = 0.09). There was also no significant main effect for Adjective type used with Noun type (F (1, 72) = 1.41, p = 0.24) – negative/non-negative adjectives used with hand-related nouns (M = 114.1, SD = 183.4) vs. negative/non-negative adjectives used with non-hand-related nouns (M = 73.3, SD = 69.1) and no significant interaction effect for Adjective type and Noun type (i.e., negative and non-negative adjectives that were used with either hand-related or non-hand-related nouns (F (1, 72) = 0.27, p = 0.60). For Thorndike-Lorge written frequency, there was no significant main effect of word category (F (3, 103) = 1.07, p = 0.36) – hand-related nouns (M = 356.4, SD = 346.8) vs. non-hand related nouns (M = 738.3, SD = 158.9) vs. negative adjectives (M = 432.9, SD = 775.3) vs. non-negative adjectives (M = 662.2, SD = 946.0) and no significant main effect of Adjective type (F (1, 65) = 1.20, p = 0.28). There was no significant main effect for Adjective type used with Noun type (F (1, 65) = 1.96, p = 0.17) – negative/non-negative adjectives used with hand-related nouns (M = 727.2, SD = 129.9) vs. negative/non-negative adjectives used with non-hand-related nouns (M = 407.6, SD = 293.9) and no significant interaction effect for Adjective type and Noun type (F (1, 65) = 0.85, p = 0.36).

Verbal frequency was examined using the Brown Verbal Frequency scale (1984). Here, there was no significant main effect of word category (*F* (3, 94) = 0.902, *p* = 0.44) – hand-related nouns (*M* = 5.0, *SD* = 5.7) vs. non-hand related nouns (*M* = 12.9, *SD* = 25.6) vs. negative adjectives (*M* = 17.1, *SD* = 27.0) vs. non-negative adjectives (*M* = 15.9, *SD* = 25.1) and no significant main effect of Adjective type (*F* (1, 62) = 0.01, *p* = 0.97). There was also no significant main effect for Adjective type used with Noun type (*F* (1, 62) = 0.85, *p* = 0.36) – negative/non-negative adjectives used with hand-related nouns (*M* = 19.4, *SD* = 32.9) vs. negative/non-negative adjectives used with non-hand-related nouns (*M* = 14.1, *SD* = 18.0) and no significant interaction effect for Adjective type and Noun type (*F* (1, 62) = 0.98, *p* = 0.33).

For number of syllables, there was no significant main effect of word category (*F* (3, 114) = 2.06, *p* = 0.10) – hand-related nouns (*M* = 1.4, *SD* = 0.58) vs. non-hand related nouns (*M* = 1.7, *SD* = 0.67) vs. negative adjectives (*M* = 1.8, *SD* = 0.70) vs. non-negative adjectives (*M* = 1.7, *SD* = 0.75) and no significant main effect of Adjective type (*F* (1, 74) = 0.30, *p* = 0.58). There was also no significant main effect for Adjective type used with Noun type (*F* (1, 74) = 2.61, *p* = 0.11) – negative/non-negative adjectives used with hand-related nouns (*M* = 1.6, *SD* = 0.54) vs. negative/non-negative adjectives used with non-hand-related nouns (*M* = 1.9, *SD* = 0.84) and no significant interaction effect for Adjective type and Noun type (*F* (1, 74) = 1.37, *p* = 0.25). The hand-related nouns (*M* = 576.1, *SD* = 46.2) and non-hand-related nouns (*M* = 530.0, *SD* = 96.0) were also matched for imageability (*p* = 0.70) as per the MRC database (Coltheart, 1981). The 40 pseudo adjectives were randomly generated in Microsoft Excel (version 16.0) from the letters that comprised the negative and non-negative adjectives. The pseudo words were manually matched for number of letters with the negative and non-negative adjectives.

3.1.1.3 Design

The experiment used a 2 x 3 x 2 repeated-measures design. The three independent variables were Mask (masked/unmasked), Adjective type (pseudo/negative/non-negative), and Noun type (hand-related/non-hand-related), and the dependent variable was participants' RTs during the 12 different experimental conditions (masked/pseudo adjective/hand-related noun; masked/pseudo adjective/non-hand-related noun; masked/negative adjective/hand-related noun; masked/negative adjective/non-hand-related noun; masked/non-negative adjective/hand-related noun; masked/non-negative adjective/non-hand-related noun; unmasked/pseudo adjective/hand-related noun; unmasked/pseudo adjective/non-hand-related noun; unmasked/negative adjective/hand-related noun; unmasked/negative adjective/non-hand-related noun; unmasked/non-negative adjective/hand-related noun; unmasked/non-negative adjective/non-hand-related noun).

3.1.1.4 Procedure

All testing took place in a dimly lit testing cubicle at MU`s Department of Psychology. Here, the participant sat on a comfortable chair in front of a desk approximately 55 cm from a computer screen. Each participant was first provided with a consent form and an information sheet that outlined the general nature of the experiment. After providing consent and completing the Handedness Inventory Form (Oldfield, 1971), participants were informed that the experiment consisted of a number of trials, and that each would present words in the centre of the screen. They were instructed to read the words carefully and to respond – by pressing the spacebar on the computer keyboard with their right hand only – to a green GoSignal that would appear on each trial. Participants were also informed that some trials would contain questions, and here, they would be required to decide (Y for yes, N for no) whether a presented word had appeared earlier in the trial. The instructions for the experiment were then presented onscreen, and the experimenter ascertained if each participant understood the task. The experiment began when the participant pressed the spacebar on the computer keyboard.

The experiment consisted of two blocks of 120 trials (one unmasked and one masked) which were presented in a counterbalanced order. Half the participants were presented with the unmasked trials first and the other half with the masked trials first. All items were presented in the centre of the screen, and all stimuli were displayed in black Courier New size 32 font on a silver background. The entire experiment was presented via *EPrime* Psychology Software Tools, version 2.0. (2018) on a 15-inch standard 4:3 ratio computer screen. Each unmasked trial commenced with a fixation cross that was presented for 1000 ms. An adjective then appeared for 500 ms and was followed by a noun, which was also presented for 500 ms. A green circle (the GoSignal cue to respond) then appeared after a random interval of between 0-200 ms – designed to prevent participants anticipating the appearance of the GoSignal. The GoSignal remained onscreen for 1000 ms and was followed by a blank screen, which was also presented for 1000 ms. At the end of 13 of the trials (on approximately 10%), to assess whether or not participants were focussed, another word was presented. Participants had to decide whether this word had been presented earlier in the trial. They responded by pressing Y for Yes or N for No on the computer keyboard (see Figure 3.1). The experiment then moved on to the next trial. Each unmasked trial took between 4000-4200 ms each (i.e., up to 4.2 seconds) to complete, and the block took approximately 10-15 minutes to complete. Participants were allowed to take a break halfway through each block (i.e., after 60 trials). The experiment continued when participants pressed the spacebar.

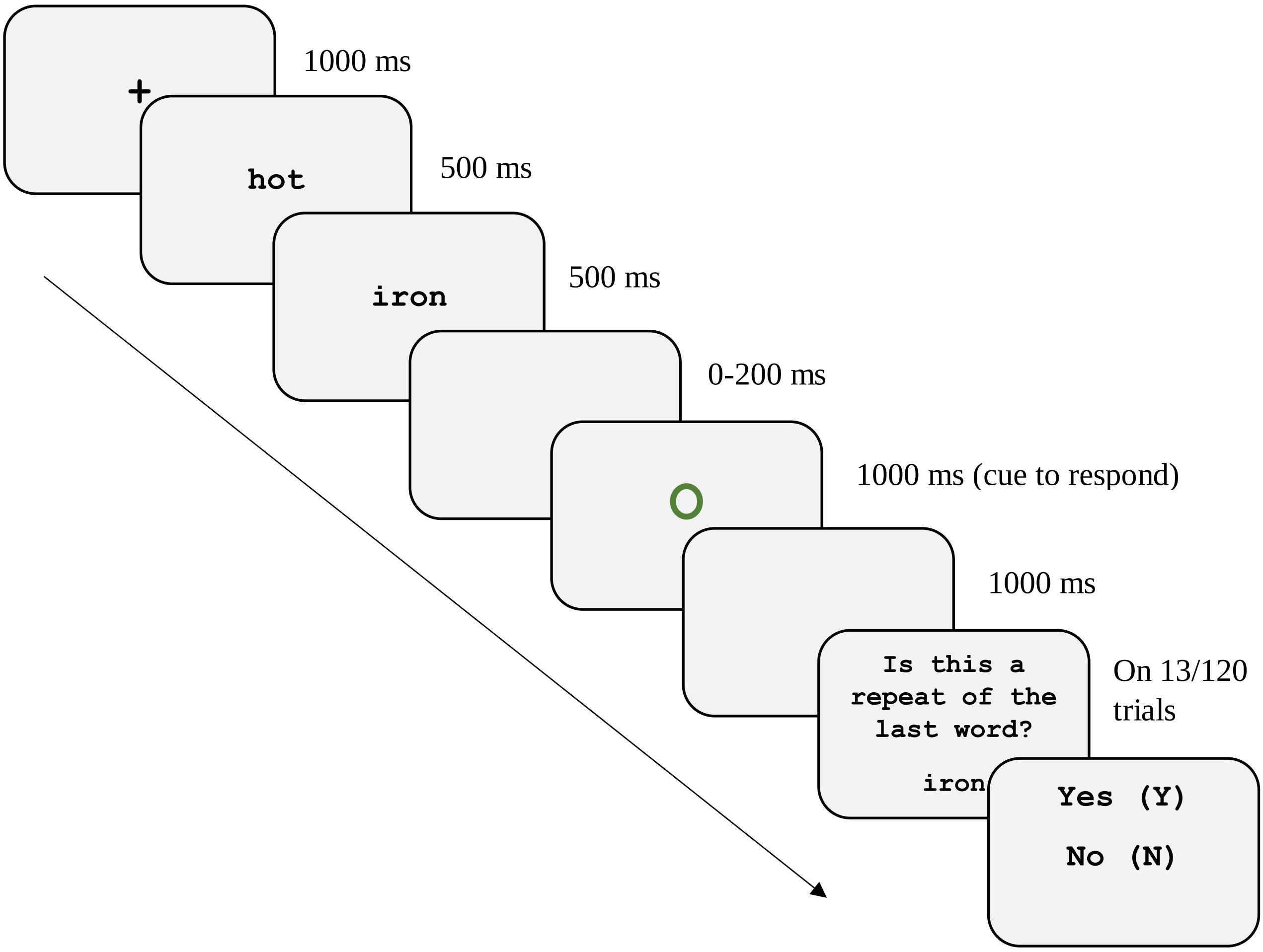


Figure 3.2. Example of an unmasked trial. Fixation cross appeared for 1000 ms before each adjective (e.g., *hot*) and noun (e.g., *iron*) appeared for 500 ms each. The GoSignal (green circle – cue to respond) appeared between 0-200 ms later and remained onscreen for 1000 ms. A blank screen appeared for 1000 ms. Repeated word questions were pseudo-randomly presented at the end of approx. 10% of trials.

Masked trials also commenced with a 1000 ms fixation cross. A series of 12 hashtags then appeared for 500 ms (e.g., ############), before an adjective (e.g., *small*) was presented for 50 ms. A second identical mask was presented for 100 ms – a noun (e.g., *iron*) was then presented for 500 ms. The GoSignal (cue to respond) appeared between 0-200 ms later for 1000 ms before a blank screen appeared for 1000 ms (see Figure 3.2). Repeated word questions were also pseudo randomly presented on 13 of the masked trials, and participants had to decide whether the presented word had just appeared. Participants were also allowed a break between the completion of the first block and the beginning of the second.

3.1.1.5 Statistical analyses

All preliminary analyses were performed using Microsoft Excel, version 16.0. Firstly, participants` accuracy in relation to the 26 repeated word questions was calculated. Here, the threshold for accuracy was set at 85 % (see Gough et al., 2012). The accuracy for two participants was below the 85% threshold, so their data were removed before the final analyses. Another participant responded less than 85% of the time during the 240 trials, so their data were also removed. The remaining 40 participants had a mean accuracy of 97% (*SD* = 3.87) for the repeated word questions and a 97% response rate (*SD* = 2.53) during the 240 trials. A mean response time (RT) across all trials was then calculated for each of the 40 participants, and all individual responses that were 2 standard deviations (SDs) above or below this mean were excluded from the analyses. On average, 94.1% of participants` responses were within 2 SDs of their individual mean times. These data were then transferred into IBM SPSS, version 25, where a 2 x 3 x 2 repeated-measures ANOVA was performed. The ANOVA tested for main effects of Mask, Adjective type, and Noun type and for interactions between factors. $P < 0.05$ was taken as significance, and where appropriate, a star-based system displaying significant differences was used on the figures (* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$).

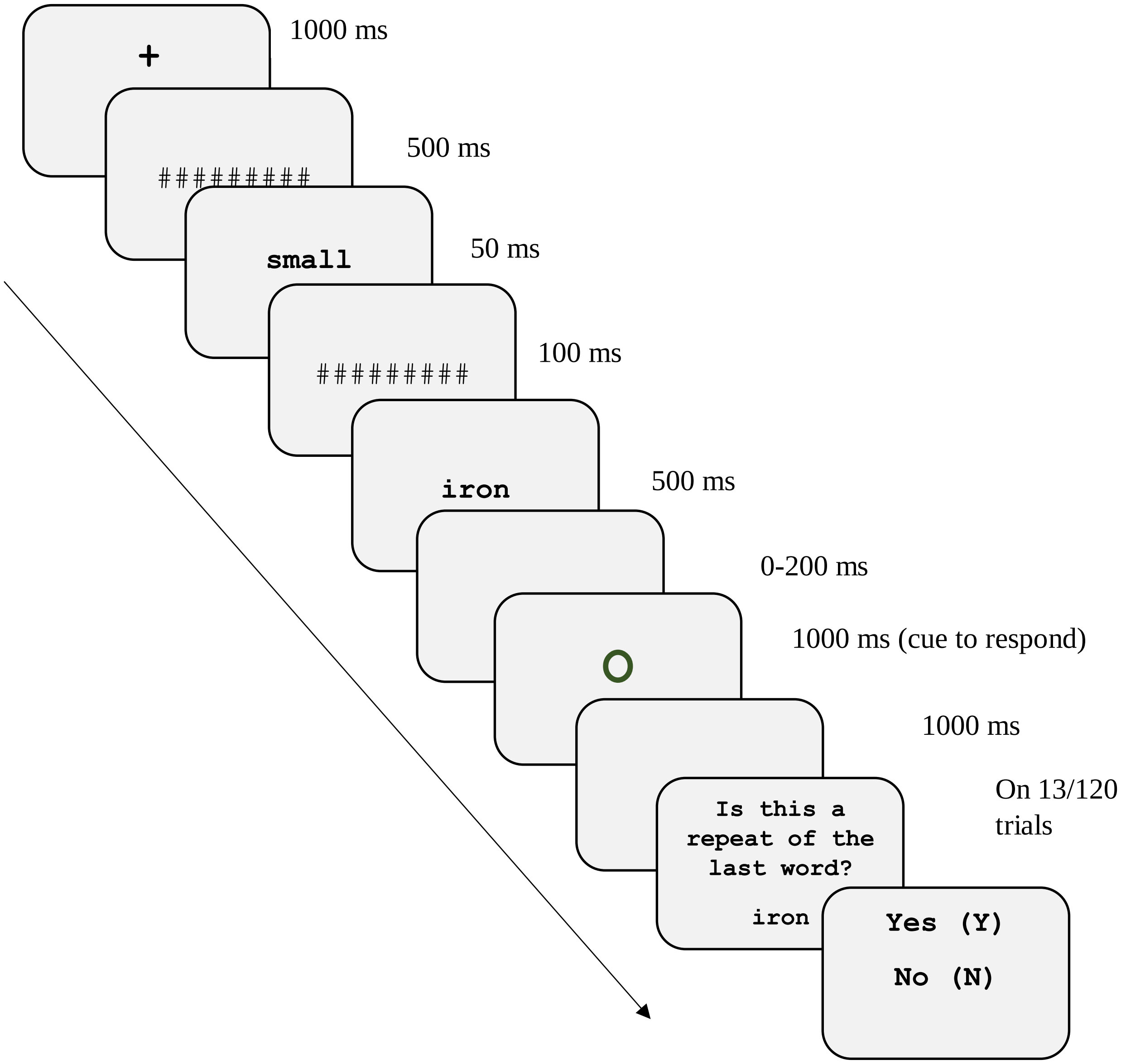


Figure 3.2. Example of a masked trial. Fixation cross appeared for 1000 ms before the first mask appeared for 500 ms. An adjective (e.g., *small*) was then presented for 50 ms before a second mask appeared for 100 ms. A noun (e.g., *iron*) then appeared for 500 ms. The GoSignal appeared between 0-200 ms later and remained onscreen for 1000 ms before a blank screen appeared for 1000 ms. Repeated word questions were pseudo-randomly presented at the end of approx. 10% of trials.

3.1.2 GoSignal results

Mean RTs for each condition were first calculated (see Table 3.1); data were then entered into the 2 (Mask = masked/unmasked) x 3 (Adjective type = pseudo/negative/non-negative) x 2 (Noun type = hand-related/non-hand-related) repeated measures ANOVA.

Table 3.1.

Mean RTs and SDs (ms) for each experimental condition.

Condition	N	Mean	SD	Min	Max
MaskedNegativeHand	40	382.4	86.7	209.73	566.81
MaskedNegativeNonHand	40	385.4	84.6	223.89	561.42
MaskedNonNegativeHand	40	381.5	87.3	176.76	560.05
MaskedNonNegativeNonHand	40	383.9	83.9	200.28	560.58
MaskedPseudoHand	40	370.4	81.1	222.3	547.7
MaskedPseudoNonHand	40	381.6	90.4	203.0	613.56
UnmaskedNegativeHand	40	369.9	82.4	198.4	548.8
UnmaskedNegativeNonHand	40	365.7	78.8	207.42	562.55
UnmaskedNonNegativeHand	40	362.7	78.1	202.18	564.06
UnmaskedNonNegativeNonHand	40	367.9	79.4	193.0	561.85
UnmaskedPseudoHand	40	367.7	77.5	227.05	511.26
UnmaskedPseudoNonHand	40	372.9	82.5	204.15	564.77

The ANOVA showed no significant main effect for Mask (F (1, 39) = 2.70, p = 0.10), although RTs were quicker during unmasked trials (367.8 ms) vs masked trials (380.9 ms) – see Figure 3.3. There was also no significant main effect for Adjective type (F (2, 78) = 0.43, p = 0.63, see Figure 3.4) – the mean RT for pseudo adjective trials was 373.1 ms, while negative adjective trials had a mean RT of 375.8 ms, and non-negative adjectives had a mean RT of 374.0 ms.

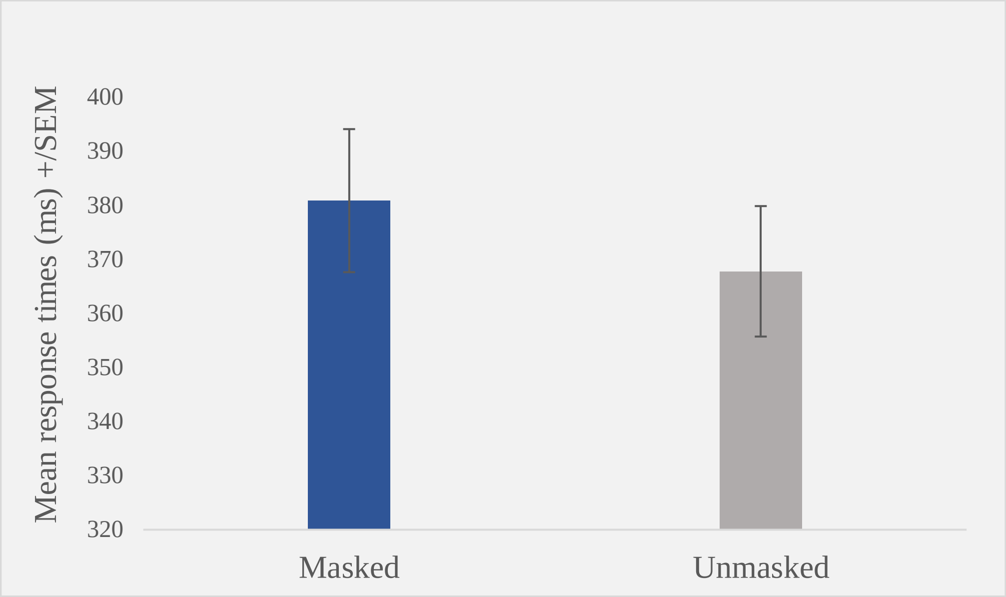


Figure 3.3. Mean RTs during masked and unmasked trials. Error bars represent the standard error of the mean (SEM).

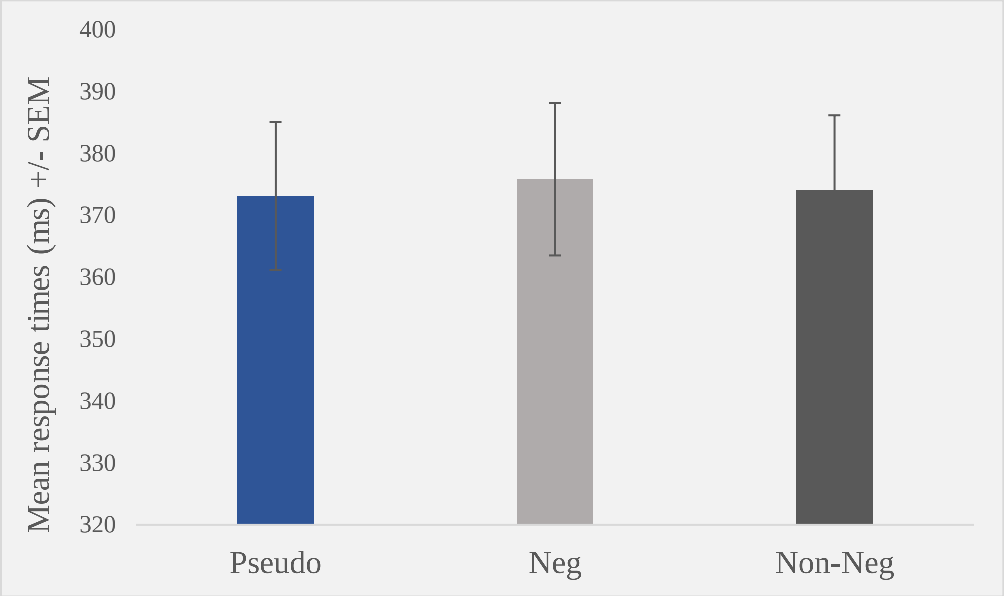


Figure 3.4. Mean RTs during trials with pseudo, negative, and non-negative adjectives. Error bars represent the standard error of the mean (SEM).

The ANOVA did reveal a significant main effect for Noun type (*F* (1, 39) = 4.31, *p* = 0.04, η² = 0.09) as highlighted in Figure 3.5 – participants were quicker to respond during trials with hand-related nouns compared to trials with non-hand related nouns (372.4 ms vs. 376.2 ms, respectively). There was also a trend towards an interaction effect between Mask and Adjective type (*F* (2, 78) = 2.52, *p* = 0.08). Here, pseudo adjectives in the masked conditions elicited quicker RTs than both negative and non-negative adjectives (375.9 ms vs. 383.9 ms vs. 382.7 ms, respectively). The opposite trend was observed during the unmasked conditions, as pseudo adjectives elicited longer RTs than both negative and non-negative adjectives (370.3 ms vs. 367.8 ms vs. 365.30 ms, respectively). There were no significant interaction effects between Mask and Noun type (*F* (1, 39) = 0.83, *p* = 0.36); Adjective type and Noun type (*F* (2, 78) = 1.52, *p* = 0.22); or Mask, Adjective type, and Noun type (*F* (2, 78) = 0.83, *p* = 0.44).

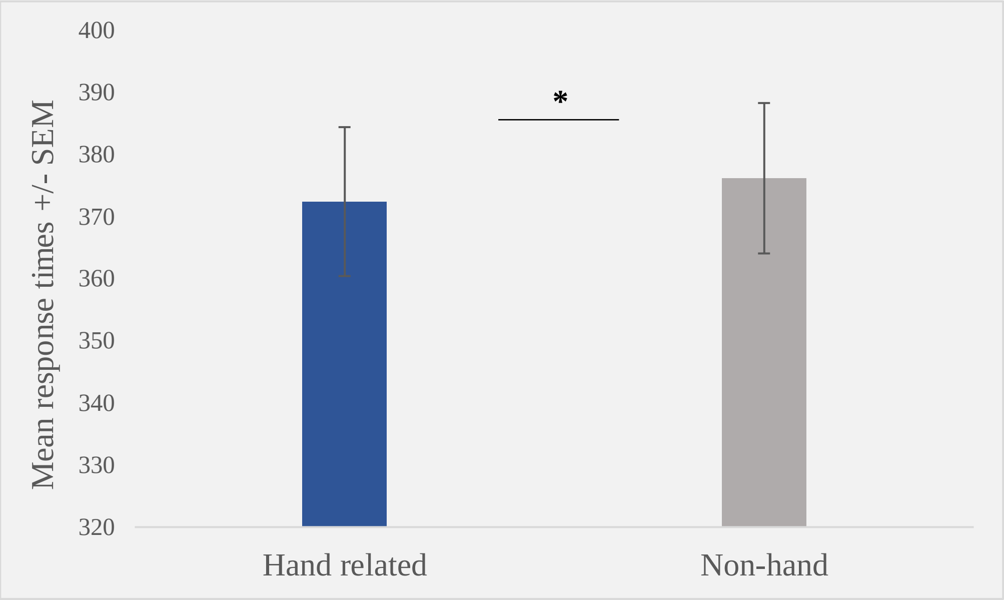


Figure 3.5. Mean RTs for Noun type. Significant difference during trials with hand-related and non-hand related nouns is at 0.04. Error bars represent the standard error of the mean (SEM).

We also performed a separate analysis to examine the effect of Noun type more closely across conditions. In this analysis, we tested whether or not the difference between levels of hand relatedness changed across different experimental conditions. For example, a positive difference in reaction time between hand-related and non-hand-related items (non-hand related minus hand related) would be expected for the pseudo adjective conditions, as hand-related nouns preceded by nonsense words would be expected to elicit quicker hand RTs than non-hand related nouns preceded by nonsense words. We also tested whether or not the magnitude of this difference would change (i.e., reduce) in conditions where hand-related nouns were preceded by negative adjectives – because of the potential inhibitory effect that the negative adjectives could elicit. To examine this, we subtracted participants` mean RTs during each hand-related condition from their mean RTs during the corresponding non-hand related condition (e.g., masked/negative/non-hand-related minus masked/negative/hand-related). The difference data were then entered into a separate 2 (masked/unmasked) x 3 (pseudo/neg/non-negative adjective) repeated measures ANOVA. This analysis showed no main effect for Mask (F (1, 39) = 0.83, p = 0.37) and no main effect for Adjective type (F (2, 78) = 1.52, p = 0.22). There was also no interaction effect between Mask and Adjective type F (2, 78) = 0.83, p = 0.44).

One sample t-tests were then performed on the difference data to test for the significance of differences between hand-related and non-hand related nouns for each condition. Here, mean RT differences for each condition was compared to zero – with zero representing no difference between hand-related and non-hand related nouns for that condition (see Figure 3.6). This analysis showed that only masked pseudo adjectives were significantly different to zero (t (39) = 2.20, p = 0.03), whereas masked negative adjectives (t (39) = 0.82, p = 0.4); masked non-negative adjectives (t (39) = 0.50, p =0.6); unmasked pseudo adjectives (t

(39) = 0.91, *p* = 0.4); unmasked negative adjectives (*t* (39) = -1.13, *p* = 0.26); and unmasked non-negative adjectives (t (39) = 1.07, *p* = 0.3) were not different from zero.

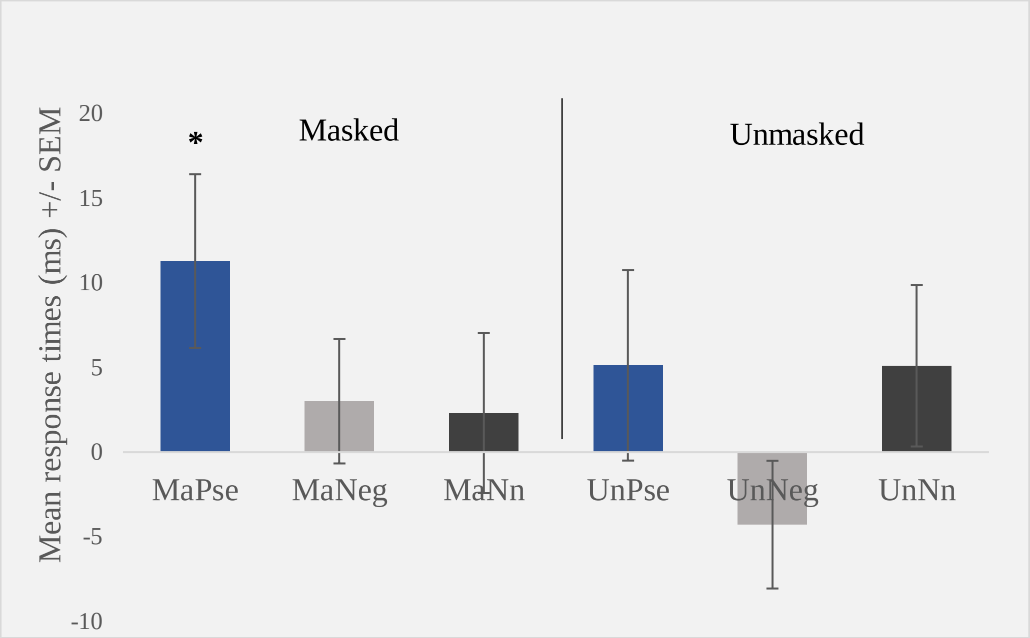


Figure 3.6. Mean differences between hand-related and non-hand related nouns for each condition in the difference data. Masked/pseudo adjectives was the only condition that differed to baseline (*p* = 0.03). Error bars represent standard error of the mean (SEM). Positive values represent conditions where hand-related noun elicited quicker RTs than non-hand related nouns.

3.1.3 GoSignal discussion

This experiment tested the effect of Adjective type on the potential facilitatory effect of hand-related nouns. To this end, participants were presented with hand-related nouns that were preceded by negative adjectives in one condition (e.g., *broken glass*), non-negative adjectives (e.g., *large glass*) in another condition, and pseudo adjectives in another (e.g., *euaulig glass*). We also presented non-hand related nouns that were preceded by negative adjectives (e.g., *awful holiday*), non-negative adjectives (e.g., *annual holiday*), and pseudo adjectives (e.g., *opttuh holiday*). Participants` hand RTs to a GoSignal that was presented between 0-200 ms after each noun were examined for each of the different conditions. This analysis revealed a significant main effect for Noun type, as participants were quicker to perform hand responses during conditions where hand-related nouns were presented.

The main effect of Noun type is in line with existing theories of language embodiment, which assert that the affordances of hand-related objects are present in nouns that refer to hand-related objects (Marino et al., 2011; Gough et al., 2013; Marino et al., 2014; Buccino et al., 2018). These affordances prime the motor cortex for acting upon the object to which the noun refers, and thus nouns referring to hand-related objects activate the cortical motor areas involved in grasping actions (Marino et al., 2011). In behavioural tasks, the hand motor activations can either interfere with hand responses that are performed during the early processing of the hand-related nouns (~150 ms) or prime hand responses that are performed approximately 400-1000 ms after the language is presented (Boulenger et al., 2006; Klepp et al., 2017). In the present experiment, participants could respond from 500-700 ms after hand-related nouns were presented and hence the facilitation to hand responses during these conditions.

We found no significant main effect for Mask and no significant main effect for Adjective type either. At first, this latter result appears to differ from the earlier finding of

Gough et al. (2013), which showed that a TMS pulse applied while processing adjectives associated with releasing actions (e.g., *slimy*) inhibited the motor excitability of the EC muscle that is associated with releasing actions. However, Gough et al. (2013) examined responses to isolated adjectives, whereas the present experiment examined responses to nouns that were preceded by adjectives. Additionally, the effects in the Gough et al. (2013) experiment were time locked to the early phase of language processing, as motor excitability was examined ~150 ms after adjectives were presented. The present experiment required participants to respond at a later stage of processing, by which point, the adjectives had already been presented between 1000-1200 ms earlier. It is possible that this difference in the timing resulted in a difference in effects and that the effect of adjectives on motor activity in the Gough et al. (2013) experiment would have disappeared by 1000-1200 ms.

However, we did hypothesise that the negative adjectives would activate the motor system in a similar way to the Gough et al. (2013) experiment by preparing the body to retract from a stimulus. We further hypothesised that this motor activity would inhibit the affordance effect of subsequently presented hand-related nouns. Therefore, the interaction between Adjective type and Noun type was of most interest – particularly in relation to negative adjectives and hand-related nouns. However, the analyses revealed that there was no interaction between these factors, so the hand-related nouns were not modified by Adjective type.

One possible explanation for this is that one or two adjectives in the negative category were not negative enough to elicit such a response. For example, words such as *hot* can have positive connotations also, and words such as *smashed* and *rusty* are not always negative or exclusively applicable to concrete objects. The experiment was somewhat limited in relation to the number of negative adjectives that could be presented, as there are much fewer adjectives with negative properties than adjectives with non-negative/positive properties. However, the three researchers that are involved in the experiment did agree that all words typified their category (i.e., negative, non-negative, hand-related, non-hand-related), so a further explanation is necessary.

It is also possible that Adjective type did not modify Noun type, because some adjectives are simply embodied to a lesser degree than the nouns and that these differences are a result of differences in sensorimotor experience. For example, concrete nouns are generally learned earliest in life, as one begins to first acquire labels for objects that are experienced on a regular basis, while adjectives are usually acquired at a slightly later stage in development (Cartmill et al., 2014; Wellsby & Pexman, 2014). Additionally, the level of experience that informs the acquisition of some adjectives may not be as concrete as the level of experience that informs the acquisition of nouns. For instance, one could plausibly have a wealth of experience with an object such as a *cup* or a *stick* but much less or no experience with objects that are *barbed* or *rusty*. Thus, responses to some of our adjectives may not reflect actual motor experience or merely reflect minimal experience, whereas it is quite probable that responses to the hand-related nouns reflect deeper levels of motor experience.

However, embodiment theories predict that the motor system should still prepare an avoidance response to the negative adjectives – many of which describe properties (e.g., *boiling*, *broken*) that are almost certainly related to sensorimotor experience. Therefore, the lack of an interaction effect between adjectives and nouns may be independent of stimuli and could be due to other factors – such as the task that the experiment employed. Specifically, the GoSignal task required participants to respond to a signal that followed each adjective/noun presentation and did not require decisions to be made about words or language to be processed semantically. Many have argued (see Aravena et al., 2012; Kemmerer, 2015; Louwerse & Jeuniaux, 2008; Sato et al., 2008; Vukovic et al., 2017) that motor simulation only occurs during tasks where the meaning of a word is necessary for performing a task and that the motor features of motor-related words are not automatically accessed. These factors could have influenced the present results and led to the lack of an interaction effect between Adjective type and Noun type. The following two experiments in the current chapter further explored this issue by examining responses to the same adjective/noun pairings using different types of tasks. Specifically, we used a lexical decision task (LDT) and a semantic decision task (SDT) – both of which require participants to make decisions about words and facilitate a slightly deeper (LDT) and much deeper (SDT) level of processing, respectively, than a GoSignal task.

To conclude, the current experiment found a significant main effect for Noun type, as participants were significantly quicker to perform hand responses during conditions where hand-related nouns were processed. However, we did not find an interaction effect between Noun type and Adjective type, as responses to hand-related nouns were not affected by the type of adjective that preceded the nouns. Our subsequent experiments will use tasks designed to test the embodiment of adjectives on a slightly deeper level to the current experiment. This should assist in elucidating more about adjective representation and allow us to test whether or not the motor system only becomes involved when lexical and/or semantic decisions need to be made about words.

3.2 Levels of processing

Embodiment of language theories propose that processing language is grounded in the actions, objects, and events to which the language refers (Barsalou, 1999; Buccino et al., 2005; Gallese, 2008; Gough et al., 2013; Marino et al., 2011; Pulvermüller, 2005). Typically, support for embodiment theories has come from studies which have shown that the motor system is involved in processing language related to actions, objects, and events (see Andres et al., 2015; Boulenger et al., 2006; Buccino et al., 2005; Gianelli et al., 2020; Gough et al., 2013; Garcia-Marco et al., 2019; Hauk et al., 2004; Klepp et al., 2017; Mirabella et al., 2012; Repetto et al., 2013; Sato et al., 2008). However, the precise role of the motor system is a major talking point within language embodiment research, and consequently, for some, the phenomenon of embodiment remains controversial. For example, while most would agree that the motor system is involved to some degree in language processing (including language embodiment critics – e.g., Hickock, 2014; Papeo et al., 2009), its exact function is still disputed. Much of this debate revolves around whether or not the motor system is automatically involved in language processing or whether or not its involvement is task and/or context dependent.

There is much evidence to support the claim of motor automaticity – via neuroimaging studies (see Hauk et al., 2004 and Tettamanti et al., 2005) and brain stimulation studies (e.g., Buccino et al., 2005; Moseley and Pulvermuller, 2014). Moreover, many behavioural experiments have found that processing words referring to hand actions (see Boulenger et al., 2006; Buccino et al., 2005; Garcia-Marco et al., 2019; Klepp et al., 2017; Sato et al., 2008) and objects upon which the hand can act (see Buccino et al., 2018; Marino et al., 2011, 2014; Zhang et al., 2016) modulated responses performed with the same body part (i.e., the hand). Generally, findings such as these have led to the conclusion that the motor activations during processing show that language and action are inter-related, as language is an embodied process.

However, other studies have found that motor activations are not necessarily automatic and that motor activity can be contingent upon task requirements and levels of processing (e.g., Connell & Lynott, 2010, 2013; Louwerse & Connell, 2011: Kuhnke 2020; Miller 2018; Papeo et al., 2009). For instance, Papeo et al. (2009) found in a TMS study that processing hand-related verbs (e.g., *I clap, I sew*) only facilitated quicker hand RTs (vs. non-hand action and non-action verbs) when participants were required to perform semantic judgments about presented words (i.e., decide whether or not the word implied a physical act). Contrastingly, no such advantage accrued for hand-related verbs when participants were merely required to indicate the number of syllables in each presented verb. Later, Aravena et al. (2012) showed that sentence structure can determine the involvement of the motor system in action-word processing. Specifically, they found that presenting action words embedded with affirmative contexts (e.g., […] *Fiona lifts the dumbbells*) increased cortical motor activity, whereas presenting the same action words embedded with negative contexts (e.g., […] *Laura doesn`t lift her luggage*) did not elicit increased cortical motor activity. From here, Aravena et al (2012) concluded that the motor-related elements of a word are not always needed when that word is processed – suggesting embodiment could be related to task demands. Potentially, though, the Aravena et al. (2012) study also highlights how negative contexts can reduce motor activity.

A study by Cuccio et al. (2014) further found that context can moderate the involvement of the motor system in action-word processing – via the finding that hand-related words only facilitated quicker hand RTs when placed within literal sentences, but not in abstract sentences – again, calling into question the automaticity of the motor system. In addition, findings from Louwerse and Connell (2011) have suggested that sensorimotor activity may not always be necessary to semantically process language and that levels of processing can impact RTs. In their work, Louwerse and Connell presented a series of phrases referring to different sensory modalities (e.g., visual – *moth can be speckled;* haptic – *satin can be smooth;* auditory – *fire* *can be crackling*; olfactory – *dog can be smelly*; gustatory – *cola can be sweet*), and participants performed a hand response as to whether statements were true or false. The analysis showed that for quicker hand responses, switching between some modalities (i.e., haptic and visual; olfactory and gustatory) did not elicit a reduction in RTs. The authors proposed that this resulted, as switching in these instances was facilitated via linguistic/semantic relations; thus, processing occurred at a shallower level (Louwerse & Connell, 2011). However, a cost to RTs was observed for longer hand response times – as, according to the authors, here, different *sensory modalities* were engaged during simulation, as linguistic relations were insufficient. Taken together, these findings suggest that embodiment could be related to deeper levels of semantic processing, and that shallower processing does not always involve sensory and motor regions – a claim which found further support in a later study by Connell and Lynott (2013). These types of findings along with others (see Dilkina et al., 2010; Sato et al., 2008; Simmons et al., 2008; van Dam et al., 2010: Yap et al., 2008) have implied that motor involvement in language processing could be task/context dependent and not automatic.

Therefore, currently, it is unclear as to whether the motor system is automatically involved in language processing or whether its involvement is dependent upon task requirements and levels of processing; thus, the exact role of the motor system in language processing is still contested. The next set of experiments were designed to try to shed some light on this issue. Specifically, to try to address the question of whether or not motor involvement in language processing is influenced by task demands, we presented two behavioural experiments using independent groups of participants. One group undertook a *lexical decision task* (LDT) – using the same adjective/noun stimuli that we used in the GoSignal experiment. Here, we presented trials containing adjectives related to avoidance (e.g., *boiling*, *barbed*), which, according to embodiment, should prepare a retraction of the hand motor area – followed by nouns referring to manipulable objects (e.g., *pot, wire*), which should facilitate a quicker hand RT. Overall, our main interest was whether or not the preceding adjectives would inhibit the hand RTs that would be expected for hand-related nouns related to approach. However, the GoSignal task did not require participants to make decisions about the nouns; here, we found that Adjective type did not modify subsequent hand RTs to hand-related nouns. In the LDT (online), participants were required to decide – via a hand response – whether the second letter string in each trial (i.e., a noun or a pseudonoun) was a real word. As such, the level of processing required to respond to noun stimuli in the LDT was slightly deeper than in our earlier GoSignal task (see General Methods for a review of different tasks). Accordingly, the LDT provided an opportunity to test the theory that motor activity is task dependent; it also allowed us to examine the conditions, if any, that elicit motor activity during language processing. As with the earlier GoSignal task, our analysis tested for a main effect of Noun type. It also tested for a main effect of Adjective type – whether or not different adjectives (i.e., negative/non-negative/pseudo) influence hand RTs to subsequently presented nouns. We paid particular attention to the interaction between Noun type and Adjective type and the effect that preceding Adjective type has on hand RTs to Noun type.

To further examine the influence of a deeper level of processing, we presented a different group of participants with a *semantic decision task* (SDT) also using the same adjective/noun stimuli. The SDT required participants to read presented words (i.e., adjectives followed by nouns) and to decide whether or not the second letter string in each trial refers to an *animal* – before making a hand response. Thus, participants were required to categorise presented words, which should involve a deeper level of processing than our GoSignal and LDT experiments, respectively. Overall, this allowed for a further test the theory that motor activity in language embodiment is influenced by task requirements and levels of processing.

Lexical decision task online (LDT)

3.2.1 LDT method

3.2.1.1 Participants

A total of 135 participants completed the online LDT experiment; another 17 began the experiment but did not complete it. According to self-reports, five participants were left-handed, so their data were not included in the final analyses. The remaining 130 (55.4% female, 35.4% male, 9.2% other/non-binary – according to self-reports) were aged between 18 and 55 years (*M* = 26.2, *SD* = 9.4), were right-handed, and spoke English as a first language. Participants were primarily recruited from a virtual poster advertisement that was circulated around MU, from a research participant pool in MU`s Department of Psychology and from the researcher`s contacts. Also, some participants were recruited via *LinkedIn* and via the psychology subpages on *Reddit*. Those who were recruited from the participant pool received course credit for their participation. No participant reported issues with psychological or neurological impairment; history of epilepsy or memory issues; or history of language related disorders (e.g., dyslexia, aphasia). No financial incentives were offered for participation. The experiment received ethical approval from MU`s Social Research Ethics Sub-Committee (SRESC-2021-2420742). Additionally, due to Covid-19 restrictions, the LDT took place online.

3.2.1.2 Stimuli and materials

The stimuli of interest were the same 120 adjectives and 120 nouns that were presented in the GoSignal experiment. However, as we were utilising an LDT, we also included 60 pseudo nouns in three different conditions – these did not require a response. Specifically, we added a negative adjective/pseudo noun condition (e.g., *hot nitn*), a non-negative adjective/pseudo noun condition (e.g., *silk mbax*), and a pseudo adjective/pseudo noun condition (e.g., *lyiai* *oeeasac*). The negative and non-negative adjectives used in these conditions were comprised of half the adjectives from the other experimental conditions. The LDT was constructed in *PsychoPy* builder (version v2021.2.3) and run online *Pavlovia* – a software system for running experiments online (see General Methods for a review of both).

3.2.1.3 Procedure

A link to the experiment was provided to those in the research participation pool and those who contacted the researcher via the poster advertisement. Separately, a link to the experiment was posted on *LinkedIn* and the psychology subpages on *Reddit*. Once the participant clicked on the link, they were brought to an information page on Qualtrics (see General Methods). The information page provided some basic details about the experiment and collected some demographic information; each participant consented by clicking a box. Thereafter, they were brought to the experiment on *Pavlovia.* Here, the participant was informed that the experiment would consist of a number of onscreen trials, and that each trial would present a black letter string in the centre of the screen – followed by a second blue/lilac letter string. Further, they were instructed to read the letter strings carefully and to respond – by quickly pressing the spacebar on the keyboard with the right hand only – whenever the blue/lilac letter string ***was a real word***. They were also instructed to refrain from responding when the blue/lilac letter string ***was not a real word***. Once the participant pressed the spacebar on the computer keyboard, the experiment began.

All stimuli were presented in the centre of the screen, on a silver background, in black Courier New font. The stimulus letter height was 0.05, which means that all stimuli would appear as 1/20th the size of each participant's screen. In total, the experiment consisted of one block of 180 trials. Each trial began with a fixation cross that was presented for 1000 ms. The black letter string (i.e., a negative, a non-negative, or a pseudo adjective) was then presented for 500 ms, before the blue/lilac letter string appeared (i.e., a hand-related, a non-hand related, or a pseudo noun) – also for 500 ms. As stated, the participant was required to respond (by pressing the spacebar on their computer keyboard with their right hand only) when the blue/lilac letter string was a real word. A blank screen was then presented for 1000 ms, before the experiment moved on to the next trial (see Figure 3.7). Each trial lasted 3000 ms, and all trials took approximately 10-15 minutes to complete. After every 45 trials, participants were allowed to take a break. After each break, the experiment continued when the participant pressed the spacebar.

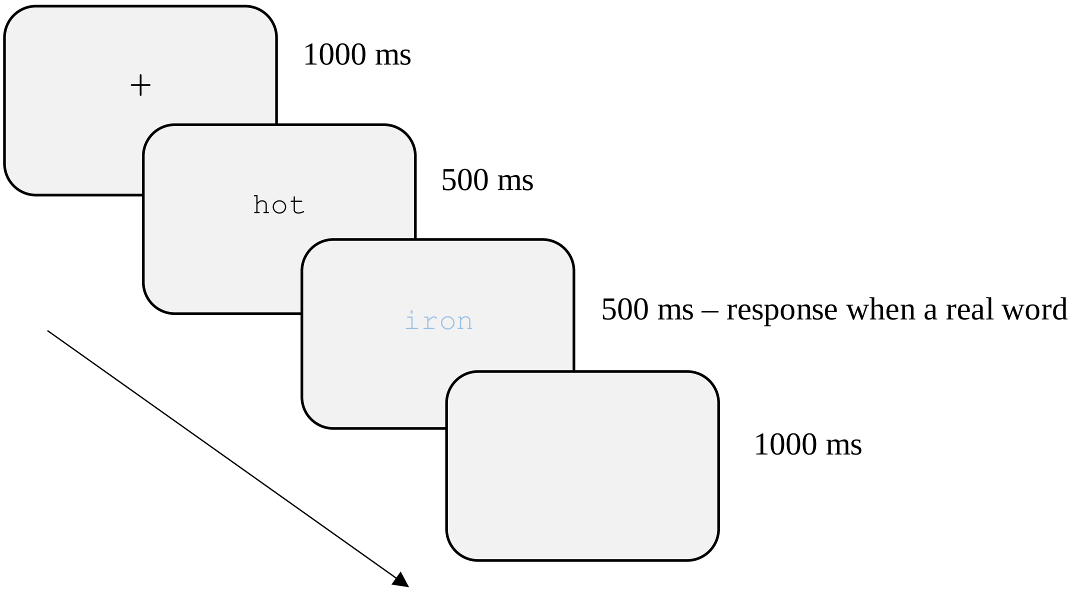


Figure 3.7. Example of an LDT trial. Fixation cross appeared for 1000 ms before an adjective (e.g., *hot*) and noun (e.g., *iron*) appeared for 500 ms each. A response was required when the noun was a real word, while a pseudo word required no response. A blank screen then appeared for 1000 ms before the experiment moved on to the next trial.

3.2.1.4 Design and statistical analyses

The experiment used a 3 (Adjective type: negative, non-negative, pseudo) x 2 (Noun type: hand related, non-hand related) repeated-measures design. Data were first cleaned for missed responses and false positives; here, a threshold of 85% was set – as per the GoSignal experiment. On average, participants had a response accuracy of 93.4%, and no participant`s overall accuracy was less than 85%. Microsoft Excel was used to compute mean RTs and standard deviations for each participant across all trials. Also, for each participant, all individual RTs that were 2 SDs quicker or slower than their individual mean were considered as errors and removed from the analysis. From the remaining data, a mean RT was computed for the 6 experimental conditions (negative hand; non-negative hand; pseudo hand; negative non-hand; non-negative non-hand; pseudo non-hand). The 3 x 2 ANOVA was then conducted to test for a main effect of Adjective type, a main effect of Noun type, and an interaction effect between Adjective type and Noun type – Bonferroni corrected *post hoc* tests were conducted as required. $P < 0.05$ was taken as significance, and where appropriate, a star-based system displaying significant differences was used on the figures (* $p < 0.05$, ****** $p < 0.01$, and ******* $p < 0.001$). As masking had no effect in the GoSignal task, we did not manipulate that variable here on in the next experiment.

3.2.2 LDT results

As highlighted in Table 3.2, mean RTs were quickest in the negative/non-hand related condition (461.9 ms) and slowest in the pseudo/hand related condition (483.1 ms).

Table 3.2

Mean RTs and SDs (ms) for each experimental condition.

Condition	N	Mean	SD	Min	Max
NegativeHand	130	465.1	64.1	365.9	660.2
NegativeNonHand	130	461.9	62.1	362.6	675.6
NonNegativeHand	130	466.3	63.9	353.7	660.3
NonNegativeNonHand	130	465.2	65.5	351.7	726.5
PseudoHand	130	483.1	68.9	371.9	727.9
PseudoNonHand	130	479.5	66.2	375.6	703.5

Data were examined in the 3 (Adjective type: negative, non-negative, pseudo) x 2 (Noun type: hand related, non-hand related) repeated-measures ANOVA. Here, a significant main effect found for Adjective type was found (F (2, 258) = 73.6, p = <0.001, η^2 = 0.36). Bonferroni-corrected t-tests showed that RTs during trials with pseudo adjectives (481.3 ms) were significantly slower than during trials with negative adjectives (463.6 ms) and non-negative adjectives (465.7 ms), respectively (see Figure 3.9.) – there was no significant differences between trials with negative adjectives vs non-negative adjectives. A significant main effect for Noun type was found (F (1, 129) = 7.1 p = 0.009, η^2= .05) – RTs during trials with hand-related nouns (471.6 ms) were significantly slower than during trials with non-hand related nouns (468.9 ms) (see Figure 3.10). No significant interaction effect was found between Adjective type and Noun type (F (2, 258) = 0.7, p = 0.48).

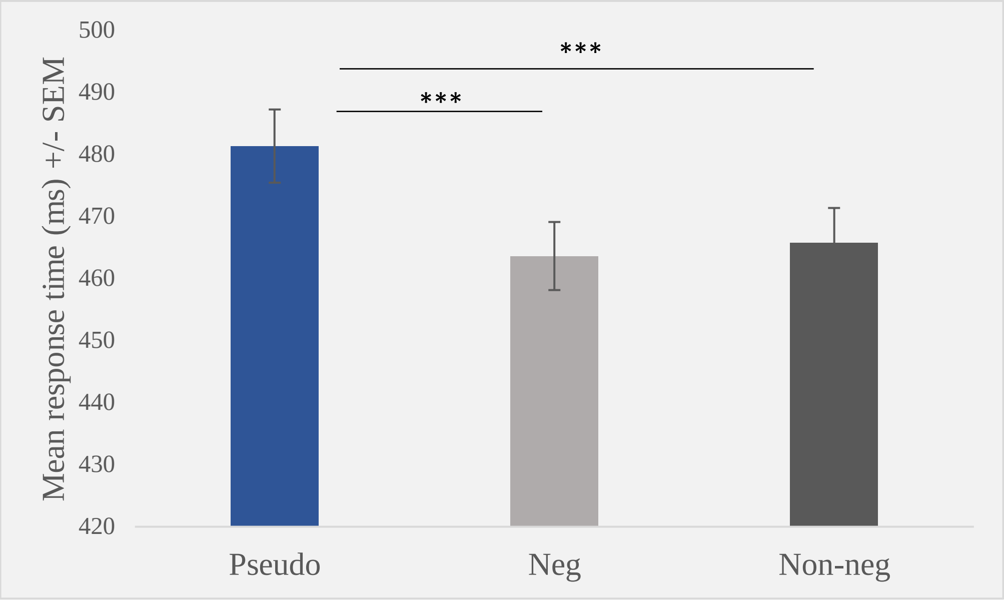


Figure 3.9. Mean RTs for Adjective type. Significant difference between pseudo and negative adjectives is at 0.001 and between pseudo and non-negative adjectives is at 0.001. Error bars represent standard error of the mean (SEM).

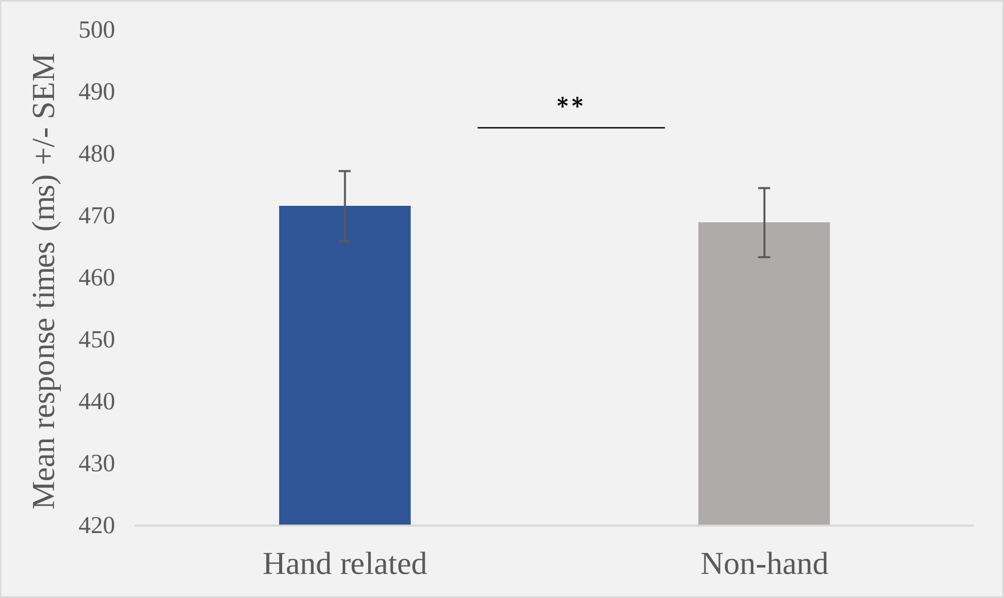


Figure 3.10. Mean RTs for Noun type. Significant difference during trials with hand-related and non-hand related nouns is at 0.01. Error bars represent the standard error of the mean (SEM).

3.3 Semantic decision task (SDT)

3.3.1 SDT method

3.3.1.1 Participants

A total of 40 participants were recruited for the in-person SDT experiment (20 females and 20 males – according to self-reports); all were aged between 18 and 50 years old (*M* = 23.2, *SD* = 6.78). All participants were recruited via a poster advertisement in MU, from a research participant pool in MU`s Department of Psychology, and from the researcher`s contacts. Those who were recruited from the participant pool received course credit for their participation. All participants were right-handed according to the Edinburgh Handedness Inventory Form (*M* = 77.1, *SD* = 16.1) (Oldfield, 1971) and spoke English as a first language. No participant reported issues with psychological/neurological impairment; history of epilepsy or memory issues; or history of language related disorders (e.g., dyslexia, aphasia). No financial incentives were offered for participation. The experiment was approved by MU`s Social Research Ethics Sub-Committee (SRESC-2019-2378905).

3.3.1.2 Stimuli and materials

The stimuli of interest were the same 120 adjectives and 120 nouns that were presented in the previous two experiments. To try to facilitate a deeper level of processing than these experiments, we also presented 20 separate negative adjectives (e.g., *fierce*) and 20 separate non-negative adjectives (e.g., *toy*) followed by an animal name (e.g., *fierce lion, toy lion)*. As participants would not be responding to the animal stimuli, we did not balance for any of the aforementioned psycholinguistic variables. The SDT experiment was constructed on *EPrime* Psychology Software Tools, version 2.0 (2018).

3.3.1.3 Procedure

As with the GoSignal experiment, all testing took place in a dimly lit cubicle at MU`s Department of Psychology. Moreover, the layout of the cubicle and the participant`s distance from the screen were the same as reported above. The participant was informed that the experiment would consist of a number of onscreen trials, and that each trial would present two strings of letters in the centre of the screen – one at a time. Further, they were informed that the second letter string would always appear in green font. They were instructed to read the letter strings carefully and to respond – by quickly pressing the spacebar on the keyboard with the right hand only – whenever the second letter string did ***not*** refer to an animal. Participants were also instructed to refrain from responding when the second letter string ***was*** an animal word. Before the experiment began, the participant took part in a practice session consisting of five trial runs. None of the letter strings presented in the trial run appeared in the main experiment (e.g., *motor*). The instructions for the experiment were then presented onscreen, and the experimenter ascertained if the participant understood the task. Once the participant pressed the spacebar on the computer keyboard, the experiment began.

All stimuli were presented in the centre of the screen in black Courier New size 32 font, on a silver background. Overall, the experiment consisted of one block of 180 trials. Each trial began with a fixation cross that was presented for 1000 ms. The first letter string (i.e., a negative, a non-negative, or a pseudo adjective) was then presented for 500 ms, before the second letter string appeared (i.e., a hand-related, a non-hand related, or an animal noun) – also for 500 ms. The participant was required to respond when the second letter string was ***not*** an animal word. A blank screen was then presented for 1000 ms, before the experiment moved on to the next trial (see Figure 3.12). Each trial lasted 3000 ms, and the task took approximately 10-15 minutes to complete. After every 45 trials, participants were allowed to take a break. After each break, the experiment continued when the participant pressed the spacebar.

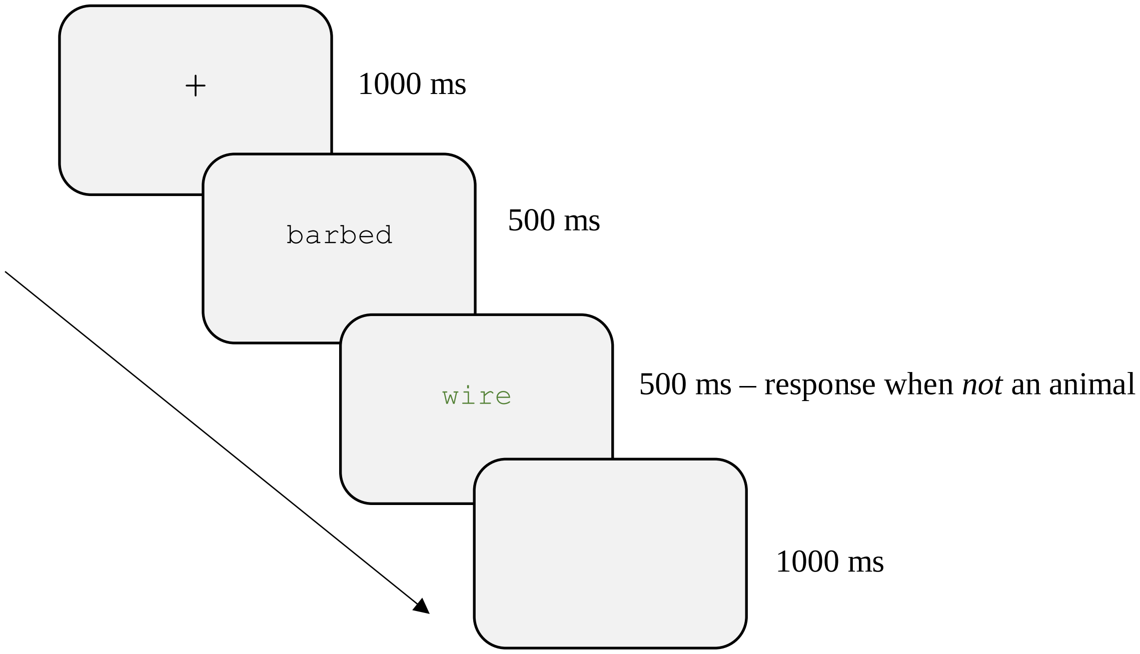


Figure 3.12. Example of an SDT trial. Fixation cross appeared for 1000 ms before each adjective (e.g., *barbed*) and noun (e.g., *wire*) appeared for 500 ms each. A response was required when the noun was a real word, while an animal name required no response. A blank screen then appeared for 1000 ms before the experiment moved on to the next trial.

3.3.1.4 Design and data analyses

The experiment used a 3 (Adjective type: negative, non-negative, pseudo) x 2 (Noun type: hand related, non-hand related) repeated-measures design. Data were first cleaned for missed responses and false positives; here, a threshold of 85% was set – as per our previous experiments. On average, participants had a response accuracy of 93.4%, and no participants` accuracy was less than 85%. Microsoft Excel was used to compute mean RTs and standard deviations for each participant across all trials. For each participant, all individual RTs that were 2 SDs quicker or slower than their individual mean were considered as errors and removed from the analysis. From the remaining data, a mean RT was computed for the 6 experimental conditions (negative hand; non-negative hand; pseudo hand; negative non-hand; non-negative non-hand; pseudo non-hand). The 3 x 2 ANOVA was then conducted to test for a main effect of Adjective type, a main effect of Noun type, and an interaction effect between Adjective type and Noun type – *post hoc* tests were conducted as required (via Bonferroni corrected t-tests). $P < 0.05$ was taken as significance, and where appropriate, a star-based system displaying significant differences was used on the figures (* $p < 0.05$, ****** $p < 0.01$, and ******* $p < 0.001$).

3.3.2 SDT results

Descriptive statistics were first computed for each experimental condition. As shown in Table 3.3, RTs were quickest in the non-negative/non-hand related condition (557.9 ms) and slowest in the pseudo/hand-related condition (584.2 ms).

Table 3.3

Mean RTs and SDs (ms) for each experimental condition

Condition	**N**	**Mean**	**SD**	**Min**	**Max**
NegHand	40	563.1	111.1	429.3	951.4
NonNegHand	40	573.5	116.8	431.2	980.6
PseudoHand	40	584.2	107.1	439.6	945.7
NegNonHand	40	558.7	108.2	428.8	909.7
NonNegNonHand	40	557.9	110.1	409.2	970.7
PseudoNonHand	40	568.7	97.5	428.8	877.4

Data were entered into the 3 (Adjective type: negative, non-negative, pseudo) x 2 (Noun type: hand related, non-hand related) repeated-measures ANOVA. The ANOVA showed a significant main effect for Adjective type (F (2, 78) = 10.31, p = < 0.001, $\eta^2 = 0.2$) – Bonferroni-corrected t-tests showed that RTs during trials with pseudo adjectives (576.49 ms) were significantly slower than during trials with negative adjectives (560.9 ms) and non-negative adjectives (565.69 ms), respectively (see Figure 3.13). A significant main effect for Noun type was also found (F (1, 39) = 19.2, p = < 0.001, $\eta^2 = 0.33$) – RTs during trials with hand-related nouns (573.6 ms) were significantly slower than during trials with non-hand related nouns (561.80 ms) (see Figure 3.14). No significant interaction effect was found between Adjective type and Noun type (F (2, 78) = 1.5, p = 0.23).

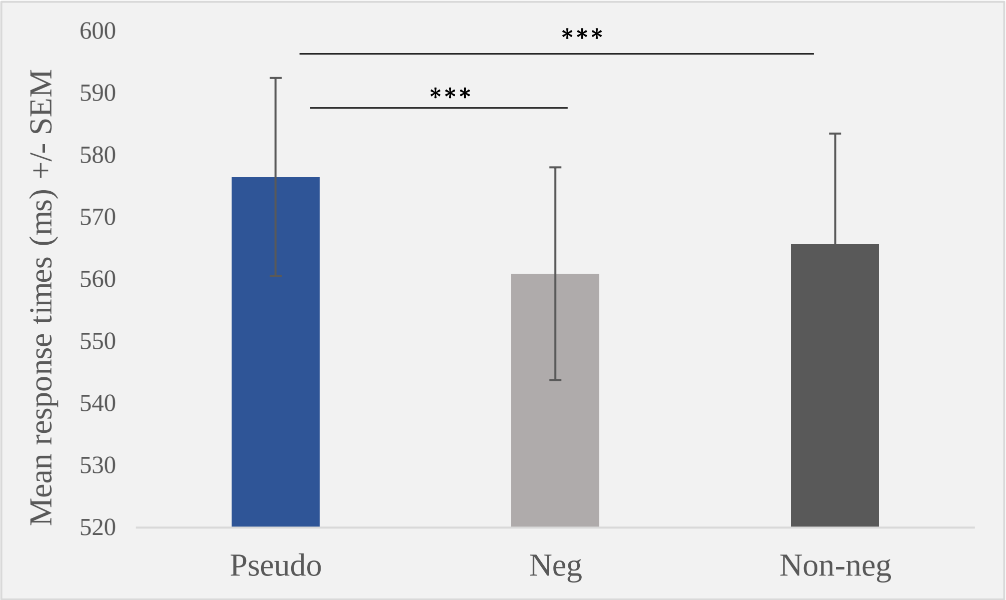


Figure 3.13. Mean RTs for Adjective type. Significant difference between pseudo and negative adjectives is at 0.001 and between pseudo and non-negative adjectives is at 0.001. Error bars represent standard error of the mean (SEM).

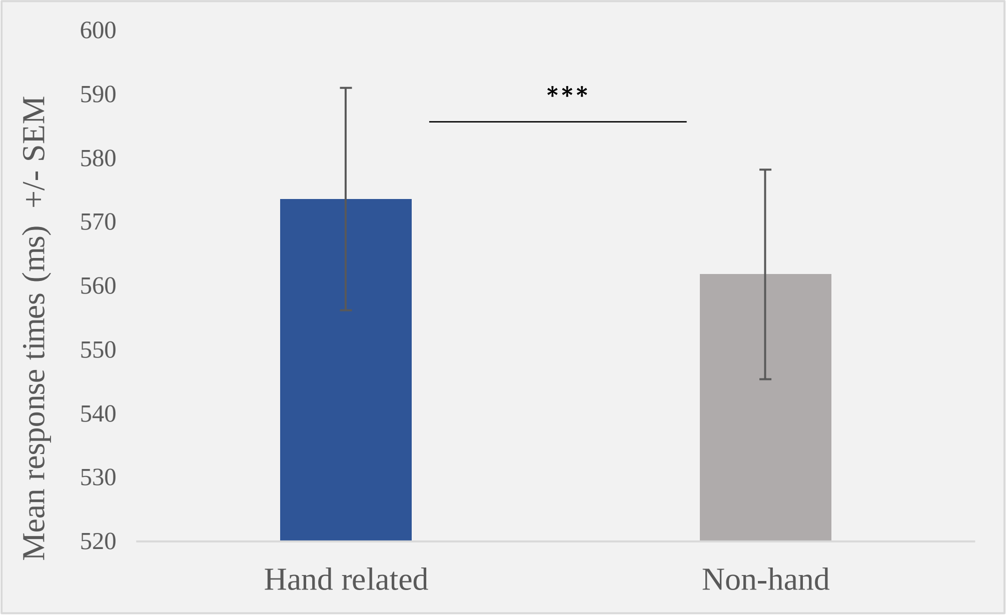


Figure 3.14. Mean RTs for Noun type. Significant difference during trials with hand-related and non-hand related nouns is at 0.001. Error bars represent the standard error of the mean (SEM).

3.4 LDT and SDT brief discussion

Here, we tested the impact of differing levels of processing on motor responses to language. Specifically, we examined the effect of Adjective type on hand responses to Noun type, using two separate tasks – a lexical decision task (LDT) and a semantic decision task (SDT) – which required slightly deeper and much deeper levels of processing, respectively, than in the GoSignal experiment. The aim of these experimental manipulations was to test the influence of levels of processing on motor responses to language and to examine the potential effect of task demands/context on the embodiment of adjectives. Overall, some interesting results were found that warrant further discussion.

In the LDT, a significant main effect for Adjective type was found – driven by quicker hand RTs during trials containing negative and non-negative adjectives. However, there was no significant difference in RTs between trials with negative and non-negative adjectives. A significant main effect for Noun type was also found in this experiment; RTs during trials with hand-related nouns were significantly slower than during trials with non-hand related nouns. There are many potential reasons for these results – which will be discussed in more detail in the general discussion for this chapter – but they will be briefly addressed here.

One such reason for the main effect for Adjective type in the LDT experiment could be that the presentation of real adjectives (either negative or non-negative) combined with task demands (responding only when the second letter string is a real word) primed participants` responses. Explicitly, the presentation of a negative or non-negative adjective as the first letter string could have allowed participants to guess that a real word (a noun) was quite likely to follow, and in that regard, the hand response to the noun could have been influenced by what preceded. For example, in the LDT, a real noun followed the presentation of a negative or non-negative adjective on 80/120 trials, whereas a pseudo noun followed only 40/120 times. Thus, it was twice as likely that a real noun would follow a real adjective, and this could have primed participants for a quicker subsequent response during trials containing negative and non-negative adjectives. Arguably, this explanation finds further support via the finding that trials with pseudo adjectives elicited longer RTs than trials with either type of real adjective. As pseudo adjectives were followed by a hand-related noun, a non-hand related noun, and a pseudo noun exactly 20 times each – this could have made it much more difficult to predict what would come next in these trials. These factors could have driven the main effect for Adjective type in the LDT experiment.

The main effect for Noun type – in the opposite direction to the effect in the GoSignal experiment (i.e., slower) could be explained via task demands. For example, as stated, and is common to many LDTs, participants were required to respond only when the (second) letter string was a real word; thus, responses depended upon discriminating real nouns from pseudo nouns. However, in the LDT, the participant could respond from the instant the noun/pseudo noun appeared onscreen, and this could have resulted in a motor cost. Specifically, in the LDT (and indeed in the SDT), the dual cost of the motor system processing a hand-related word whilst also facilitating a hand response could have resulted in slower RTs. Taken together, therefore, it could be argued that task demands influenced results from the LDT experiment.

The SDT experiment examined the same stimuli and also found some interesting results. As with the LDT experiment, a significant main effect for Adjective type was found – again, driven by quicker hand RTs during trials with negative and non-negative adjectives. These findings are also arguably partly due to task demands, as it is possible that the negative and non-negative adjectives may have provided a clue that what was to follow was twice as likely to be a real word and not an animal word. For example, in a similar manner to the LDT design, a negative adjective and a non-negative adjective was followed by a non-animal word on 80/120 trials, whereas an animal word followed on 40/120 real adjective trials. Thus, trials with real adjectives could have primed a quicker response – regardless of the type of noun that followed. Contrastingly, trials with pseudo adjectives were followed by a hand-related noun, a non-hand related noun, and a pseudo noun exactly 20 times each, which could have made it much more difficult to predict what would come next. Also, similarly, a significant main effect for Noun type was found in the SDT; trials with hand-related nouns elicited slower RTs than non-hand related nouns. As with the LDT, this could be explained via the dual effort of the motor system having to process the hand-related word and facilitate a hand response. This further suggests that task demands could have influenced the processing of motor-related language – this will be discussed in more detail in the general discussion for this chapter. It is also noteworthy that the LDT and SDT returned very similar findings, even though one was in person, and one was run online. This will also be discussed further in the discussion section for this chapter.

3.5 Discussion

Many prior experiments on language embodiment tested responses to verbs and nouns only, so the current chapter aimed to expand existing research by examining a much lesser studied word category – *adjectives*. Specifically, we tested whether or not processing different adjective types impacted hand responses to subsequently presented noun types. For example, previous research had shown that processing nouns referring to objects upon which the hand can act (e.g., *iron, pot*) either inhibits or facilitates a subsequent hand RT – depending upon task and when the response is performed (see introduction for details). Reportedly, this accrues as the hand-related noun provides the motor system with the potential to act upon the object in question, and this can either disrupt or prime a subsequent motor response. Our experiments explored what happened to hand RTs when the potential of the motor system to act upon an object was inhibited by a preceding negative adjective. Explicitly, we examined what would happen to a hand RT to the word *iron* when it was preceded by the adjective *hot* and what would happen to a hand RT to the word *pot* when it was preceded by the adjective *boiling*. In testing this phenomenon, we aimed to understand more about adjective representation specifically and motor-related language overall. We also hoped to build on earlier work of Gough et al. (2013) who examined motor activity during the processing of single adjectives related to avoidance or approach.

Additionally, we examined the impact of differing levels of processing on language representation – given the potential dispute that surrounds this issue. Specifically, we tested the degree to which task type influenced motor responses to language, with the aim of establishing whether or not motor activity during language processing was automatic or related to task requirements. To this end, using three different types of tasks – each requiring different levels of processing – we tested the potential inhibitory effect of negative Adjective type on the expected effect for hand-related nouns. All three experiments returned interesting results.

The GoSignal experiment used a shallow level of processing to test whether or not Adjective type could modify hand responses to Noun type. Here, participants simply had to respond with the hand each time a green signal appeared onscreen, and each green signal followed the presentation of an adjective followed by a noun. The experiment was designed to assess the *automatic* processing of language, as it merely required participants to read words that appeared onscreen and did not require decisions to be made about words. In the GoSignal experiment, we found a significant main effect for Noun type – trials containing hand-related nouns elicited quicker hand RTs to the green signal than trials with non-hand related nouns. In line with previous research, quicker hand RTs would be quite expected, given the time delay between noun presentation and when the participant could respond (i.e., from between 500-700 ms after noun presentation). However, of most interest was whether or not the hand-related effect was modified by the adjective that preceded, as it was hypothesised that negative adjectives (e.g., *sharp*) may prepare the motor system for avoidance, which would reduce the subsequent advantage for hand-related nouns. The analysis showed that no such interaction occurred.

In attempting to explain these results, it was postulated that perhaps some our adjectives (e.g., *hot, smashed*) were not negative enough to inhibit the potential of the motor system to act. Further, we proposed that possibly some adjectives were simply less related to motor experience than nouns. However, we also suggested that results could have been influenced by task demands, and that maybe the shallower processing levels of the GoSignal task had an impact. Specifically, as had been proposed by some (e.g., Aravena et al., 2012; Cuccio et al., 2014), it was mused that motor activity during language processing tasks could depend upon context and/or task requirements, and that motor activity could be due to having to make decisions about presented stimuli. Both the LDT and the SDT set out to test this hypothesis

– using the same stimuli as in the GoSignal experiment but with different tasks and different levels of processing.

When testing the same stimuli using an LDT and an SDT, some interesting results were found that differed to the ones from the GoSignal experiment. For example, a significant main effect for Noun type was found in the LDT and the SDT, and a significant main effect for Adjective type was also found in both. The main effect for Noun type was driven by slower RTs during trials with hand-related nouns, while the effect for Adjective type was driven by quicker RTs during trials containing negative and non-negative adjectives only. As briefly discussed, the adjective finding could have resulted from task demands and the very layout of the LDT and the SDT. For instance, in the LDT and SDT, participants had to respond with the hand as quickly as possible each time the second letter string was a real word or not an animal, respectively, and each letter string in question was either preceded by a negative, a non-negative, or a pseudo adjective. However, in both experiments, two out of every three trials that presented negative or non-negative adjectives as the first letter string were followed by a real noun, and this could have primed participants that what would follow was a real word/not an animal word. Conceivably, this could have elicited quicker hand RTs during trials where negative and non-negative nouns appeared. It is also possible that trials containing pseudo adjectives (i.e., nonsense words) may have caused slight confusion and this resulted in slower subsequent RTs.

The main effect for Noun type in the LDT and SDT experiments was driven by slower hand RTs during trials with hand-related nouns, and this finding differs to the GoSignal experiment which found quicker hand RTs during trials with hand-related nouns. However, in the LDT and SDT, the participant could respond whenever they liked to the second letter string (relative to what they recognised the second letter string to be), whereas in the GoSignal experiment, the green signal *told* participants to respond. Additionally, as discussed, the

GoSignal did not appear until between 500-700 ms after noun presentation, so responses during this experiment were performed later than in the LDT and SDT. Thus, the longer RTs to hand-related nouns in the LDT and SDT experiment could have been due to task differences and the dual cost of deciding about hand-related stimuli while concurrently performing a hand response – as has been found previously (see Fernandino et al., 2013; García-Marco et al., 2019). Accordingly, this could have eliminated the facilitatory effect for hand-related nouns that has been found in some previous studies (see Buccino et al., 2018; Marino et al., 2011, 2014; Zhang et al., 2016) and in our GoSignal experiment.

Taken together, it could be argued that task demands had an impact on our experimental findings, which further supports the claim that language embodiment can be influenced by context/task. However, it is also possible that some environmental factors had an influence on proceedings, as the LDT task was run online. Thus, for that experiment, there was no real way of controlling for factors like screen distance/size, lighting, and noise levels, and these factors could have had an impact. However, there were explicit written instructions provided to participants to take the task in a quiet room with minimal distractions. Additionally, an analysis of the number of false positives and missed responses for each participant who undertook the LDT did allow us to gauge attention to some degree, and the experiment utilised a repeated-measures design. All things considered, it seems unlikely that conducting an LDT online would elicit too much of a difference compared to conducting it in person. To shed further light on this issue, a future project could run the same experiment in person and compare their findings to the present ones. This analysis could highlight whether or not environmental context has an influence on LDT responses.

It is also simply possible that some adjective/noun associations are so strong that presenting certain adjectives followed by certain nouns would elicit similar effects in many experimental tasks – particularly ones where participants have to decide about stimuli. This proposition appears to be supported via the findings from the LDT and SDT experiments of a significant main effect for Adjective type – driven by quicker hand RTs during trials with negative and non-negative adjectives only. Though some adjective trials were also followed by pseudo nouns and animal words, respectively, they were twice as likely to be followed by a real noun. Accordingly, if the association between some adjectives and nouns is strong, this could easily have influenced the quicker responses during these trials; thus, an LDT and SDT may not be suitable to test the effect of Adjective type on hand responses to Noun type.

Overall, our results suggest that levels of processing can influence responses to motor-related language and that task demands can impact language representation. Additionally, on the one hand, the lack of a motor effect for adjectives implies that motor activity may not always be automatic during processing and may be a product of task demands. Similar results have been observed before (see Aravena et al., 2012; Dilkina et al., 2010; Kuhnke 2020; Miller 2018; Sato et al., 2008) adding further weight to the claim. Interestingly, recently, Garofalo et al. (2021) conducted experiments to test the embodiment of adjectives. In their work, participants either performed a power or precision movement that was either compatible or incompatible with presented nouns. A significant main effect for compatibility was found for artifact nouns (i.e., tools), but this effect was modified when nouns were preceded by disadvantageous adjectives (e.g., *sharp*) (Garofalo et al., 2021). Overall, this shows that, in some instances, adjectives can modify motor responses to nouns, though it must be noted that participants in the Garofalo et al. (2021) experiments also had to make decisions about stimuli.

On the other hand, though, in all three experiments here, hand motor activity was modified during trials with hand-related nouns. Though task demands and other factors may have influenced the direction of effects, the findings still support the claim that hand-related nouns can impact subsequent hand-motor activity. Consequently, the findings here add to previous studies` findings on noun processing (see Buccino et al., 2018; Marino et al., 2011, 2014; Zhang et al., 2016) and suggest that nouns could be embodied in sensory and motor pathways. Arguably, testing adjectives may be a slightly more difficult prospect; however, future experiments could try a few different methods. For example, researchers could conduct a separate pre-test to examine the strength of associations between certain adjectives and nouns. This could be achieved by providing participants with a list of adjectives and asking them to write down the first word that comes to mind. If there was convergence as to which nouns would follow, to eliminate the influence of priming, researchers should consider alternative methods. As suggested, an LDT could be run in person and results could be compared with our own online findings; this would shed some light on the potential confound of conducting an LDT online. A slightly different SDT could also be conducted requiring participants to respond whenever the second letter string refers to a concrete object, and stimuli of interest could be grouped via the same adjective and noun types. Conceivably, performance here would be slightly less taxing than performance in the current SDT. Experimenters could also run the same LDT and SDT but implement a GoSignal (as with the current GoSignal experiment), requiring participants to respond from between 500-700 ms after the second letter string is presented. It would be interesting to examine whether or not this modification reverses the slower effect for hand-related stimuli as observed in the current work.

Overall, our research provides further support for the claim that processing hand-related nouns impacts subsequent hand activity. However, whether or not subsequent hand motor activity is inhibited or enhanced appears to depend upon task demands. Additionally, in a GoSignal experiment, an LDT, and an SDT, it was found that Adjective type did not modify hand responses to Noun type; arguably, these findings are due to task demands coupled with strong adjective/noun associations. To know more about adjective representation, future work should aim to disentangle these issues.

Chapter 4

Age of Acquisition – Review and Analyses

Abstract

Embodiment of language theories propose that language and action are interrelated. *Age of Acquisition* (AoA) effects refer to the findings that words, phrases, and concepts learned before approximately 7 years old are processed quicker than stimuli learned after approximately 7 years old (Brysbaert et al., 2000). However, AoA is a factor that does not appear to have been considered by embodiment researchers, so it is not entirely clear if existing findings have been influenced by AoA. Accordingly, the current chapter reviewed a subsection of *PubMed* studies that were conducted between the years 2000-2022, which examined motor activity as single nouns, verbs, adverbs, or adjectives were processed. Our first aim was to ascertain whether or not AoA had been accounted for by researchers. If it had not been considered, an AoA norm was established for each word in the available wordlists (primarily, via Kuperman et al `s 2012 AoA ratings), and we tested the potential effect of AoA in that study. This analysis found that 14/15 studies did not control for AoA. Further analysis showed that 7/14 studies that did not consider AoA could have been influenced by the factor; the implications of these findings for language embodiment theories are discussed within.

4.1 Introduction

Theories of *language embodiment* typically propose that language and action are interrelated, and processing language is built upon experiences of the actions, objects, and events to which the language refers (Barsalou, 1999; Buccino et al., 2005; Gallese, 2008; Gough et al., 2013; Marino et al., 2011; Pulvermüller, 2005). Generally, embodiment researchers have tested the phenomenon by examining the role of the motor system in language processing. Many studies have found that processing words referring to bodily actions activates and uses the same motor areas that underpin the production of the bodily actions (see Andres et al., 2015; Boulenger et al., 2006; Buccino et al., 2005; Gianelli et al., 2020; Gough et al., 2013; Hauk et al., 2004; Mirabella et al., 2012; Repetto et al., 2013). For example, early studies by Hauk et al. (2004) and Tettamanti et al. (2005) showed that simply reading hand-related (e.g., *to wash*) and foot-related verbs (e.g., *to kick*) activated the hand and foot cortical motor regions, respectively. Furthermore, findings from behavioural experiments have shown that processing verbs referring to bodily actions can modify motor responses performed with the body part described in the actions (see Boulenger et al., 2006; Buccino et al., 2005; Garcia-Marco et al., 2019; Klepp et al., 2017; Sato et al., 2008). Studies such as Boulenger et al. (2006) and Klepp et al. (2017) found that processing hand-related verbs can either inhibit (i.e., slow down) or facilitate (i.e., speed up) hand response times (RTs), respectively, depending upon whether the hand response is performed early (within 200 ms) or later (~400 ms onwards) after word presentation. Taken together, findings from experiments on action word processing suggest that the representation of verbs describing bodily actions is closely related to the bodily actions described by the verbs, which implies that language and action are interlinking processes. This suggests that the motor system may play a functional role in language processing – an assertion which forms the foundation for many theories of language embodiment (e.g., Barsalou, 1999; Buccino et al., 2005; Gallese, 2008; Gough et al., 2013).

Language embodiment studies have also shown that the motor system is involved in processing nouns describing objects upon which the body can act – providing further support for the proposition that language and action are interrelated. For example, Marino et al. (2011, 2014) and Zhang et al. (2016) showed that processing nouns describing graspable/hand-related objects (e.g., *pencil*) modified subsequent RTs performed with the body part used to interact with the objects (i.e., the hand). The Marino et al. (2011) study found that graspable nouns *inhibited* hand RTs that were performed early after noun presentation (i.e., after 150 ms). The researchers suggested that this occurred, because at 150 ms, the hand area of motor cortex was involved in both the processing of the hand-related word and the production of the hand response. Contrastingly, Zhang et al. (2016) found that processing graspable nouns *facilitated* hand RTs when these were performed at a later point after noun presentation (~ 600 ms). At 600 ms, the graspable nouns had already been processed in the hand cortical motor area, and the prior motor activation facilitated a quicker, subsequent hand RT. Similar to verbs, these modulations highlight that processing graspable nouns can either inhibit or facilitate subsequent hand motor RTs, which suggests that the hand motor area is also involved in processing nouns related to hand actions. Overall, this implies that language and action are interrelated, and that processing language is an embodied process.

However, other factors have also been shown to elicit motor activity in language embodiment experiments, some of which relate to the non-semantic characteristics of words. For example, de Zubicaray et al. (2013) conducted a study which presented hand-related verbs, non-hand related nouns, and pseudo words containing endings that were similar to real verbs and nouns. Participants` neural activity was examined, via fMRI, as they read the words and performed a subsequent hand response to whether or not the stimulus was a noun or a verb. The most interesting finding was that hand-related verbs and verb-like pseudowords elicited increased activations in left supplementary motor area (SMA) and mid lateral primary motor cortex (de Zubicaray et al., 2013). Notably, non-hand related nouns and noun-like non words did not elicit increased activity in these regions. Accordingly, and in opposition to embodiment theories, the researchers proposed that their pseudo word activations and the motor activity that typifies many embodiment experiments are actually the result of the motor cortices` role in discriminating grammatical categories (i.e., verbs from nouns). However, this claim does not explain the many findings which have shown that processing hand-related verbs (see Boulenger et al., 2006; Buccino et al., 2005; Klepp et al., 2017), hand-related nouns (see Marino et al., 2011, 2014; Zhang et al., 2016), and even hand-related adjectives (see Gough et al., 2013) all activated and utilise the hand motor area – regardless of grammatical category.

Yet, other factors could also be influencing findings from embodiment experiments. For instance, *Frequency* refers to how regularly a word is encountered, and a word`s frequency can influence responses across various experimental tasks (Brysbaert et al., 2018; Ellis, 2002). In experiments that present written words, written frequency can be established via various databases which have calculated how often certain words appears in written texts (e.g., Kucera and Francis Database; CELEX Lexical Database) (Juhasz et al., 2019). Typically, high-frequency words elicit quicker responses than low-frequency words, as high-frequency words tend to be better known and thus processed more quickly (Monsell et al., 1989). Moreover, Brysbaert and Biemiller (2017) showed that written frequency was the greatest predictor of RT speed in lexical decision tasks (LDTs) – highlighting just how important it is to control for this variable. However, word frequency is often considered by language embodiment researchers (e.g., Buccino et al., 2005; Marino et al., 2011, 2014); thus, frequency of presented words is usually accounted for.

What has been less considered is the period within which a word, phrase, or concept has been learned – known as *Age of Acquisition* (AoA). Though there is no specific agreement, early AoA is generally categorised as before aged 6/7 years old and late AoA as after aged 6/7 years old, and the effect of early AoA can be observed across numerous tasks (see Arnon et al., 2017; Brysbaert et al., 2000; Ellis et al., 2010; Morrison & Ellis, 1995; Stadthagen-Gonzalez et al., 2004). For instance, Stadthagen-Gonzalez et al. (2004) found that RTs to early acquired words in an LDT were significantly quicker than to late acquired words. The experiment also found that words that were early acquired but low frequency elicited quicker hand RTs than late acquired, high-frequency words. A later study by Smith-Spark et al. (2012) found that participants were quicker to respond to celebrities` names (via hand RTs) that were learned early in life in comparison to later learned celebrities' names – a finding which persisted when frequency of exposure, facial distinctiveness, and celebrities` familiarity were accounted for. Additionally, Arnon et al. (2017) showed that participants were quicker to categorise the plausibility of early learned (e.g., *are you drawing*) vs. late learned phrases *(e.g., are you proud*). Thus, early AoA is a factor that can influence responses across many language experiments, but it is a factor that has not been considered by many language researchers (e.g., Buccino et al., 2018; Gough et al., 2012; Repetto et al., 2013; Willems et al., 2010), although it has by some (e.g., Garcia et al., 2019). As such, it is not entirely clear if the motor activity that typifies many language embodiment experiments is being influenced by, or is the result of, AoA. The present chapter further explored this issue by examining the potential effect of AoA on previous findings related to embodiment.

To determine the potential impact of AoA on previous language embodiment studies, a subsection of studies on the *PubMed* database from 2000-2022 was reviewed. The first aim was to establish whether or not each study had considered AoA as a potential factor. If AoA was not considered, we compared the available stimuli from each study against an established set of AoA norms (i.e., Kuperman et al `s 2012 AoA ratings) to ascertain whether or not the omission could have been a potential confounding factor in that study. This analysis allowed us to test the potential influence of AoA on previous embodied language findings.

4.2 AoA review and analysis

4.2.1 Method

4.2.1.1 Search criteria

The words *language, embodiment*, and *motor cortex* were typed into the PubMed search bar, and the *results by year* option was set between 01/01/2000 and 31/05/2022. PubMed was chosen for the review as it is one of the largest available research databases and draws from over 7,000 journals (Fiorini & Lipman, 2017). Specifically, we searched for studies that measured motor responses (with any body part) and/or cortical or bodily activity while either single verbs, nouns, adjectives, or adverbs were processed. Notably, we did not include studies that tested motor activity/responses to sentences or phrases, as potentially, these contain many more variables than with single word studies – such as eye gaze and word anticipation (see Kamide, 2008). We also eliminated studies that used only patient data – though we did consider healthy control group data within patient studies. In addition, reviews were not included in the analysis, and only studies that tested participants in their first language (i.e., L1) were considered. However, all L1 languages (i.e., non-English languages) were considered during the initial review.

4.2.1.2 Search results and analysis

From the initial search, PubMed`s database returned 152 potential studies for analysis. Thereafter, based upon the criteria outlined above, each of the 152 studies was examined to establish whether or not it was suitable for the review. Here, 42 studies were excluded, as they were not found to have measured motor activity/responses during language processing. Additionally, 41 studies examined the processing of sentences, phrases, or metaphors – these were also excluded. A further 25 papers were reviews and not experimental studies, while 6 studies tested patient samples only. Three studies were found to have measured processing in toddlers/children aged between 7-10 years old – these were not suitable, as some participants would be just about at our cut off point for early *age of acquisition*. Four further studies were found not to be supporting language embodiment – these were also excluded, while two studies examined participants` learning of a second language only and were thus excluded. Overall, this meant that 29 studies fitted within the search criteria (see Figure 4.1); we then searched these studies for their wordlists. Further, we emailed the authors who did not include their wordlists and asked if they could supply a list of the stimuli that was used in their work. Four authors responded and provided wordlist/s; however, one of the wordlists could not be used, as it did not group the words into the same categories that were used in the study. A further four authors responded but could not locate their wordlists. Nine authors did not respond to the email request.

Overall, 15 studies were left for the analyses (see Table 4.1). Subsequently, it was found that only 1/15 studies had balanced stimuli for AoA (i.e., Sokoliuk et al. (2019); interestingly, this study used Kuperman et al`s (2012) AoA ratings. A further breakdown showed that 6 of the studies tested for neural effects only, while five tested for neural and behavioural effects; three studies tested for behavioural effects only, while one used TMS and behavioural measures. Additionally, 6 studies used English words, four others used Dutch; three used German stimuli and two used Italian – all details are displayed in Table 4.1 and Appendix C.

In each individual study, an AoA norm was established for each available word– beginning with the studies that used English words as stimuli. Here, the Kuperman et al. (2012) set of AoA norms was used. For example, if a study in the review used the word *grab*, we used the corresponding AoA norm for *grab* from the Kuperman et al. (2012) list – these norms were chosen, as they have been shown to reliably correlate to other AoA norms (i.e., Dale & O'Rourke, 1981 – see Section 4.3 for more on the topic of choosing appropriate AoA norms).

The same process was followed for non-English words, but different AoA norms were used. For instance, for Italian words, Montefinese et al.`s (2019) AoA norms were used. These norms were found to have high internal reliability (0.95) and to be strongly correlated with Italian AoA norms from other studies. A set of norms from Birchenough et al. (2017) were used for German words; these norms also had high internal reliability (i.e., 0.91) and were strongly correlated with other sets of German AoA norms. Additionally, Brysbaert et al.`s (2014) validated norms were used for the Dutch wordlists. However, it should also be noted that the non-English AoA databases had much fewer norm values than the Kuperman et al (2012) database. Accordingly, we only used the non-English norm when the associated database contained values for over 50% of a study`s wordlist. If there were not enough non-English values, we used the Kuperman et al (2012) values for translations instead. In these instances, we used the English translations that were provided by the researchers; when translations were not provided, we translated the words via the Collins English dictionary online (https://www.collinsdictionary.com/) and the Cambridge English dictionary online (https://dictionary.cambridge.org/).

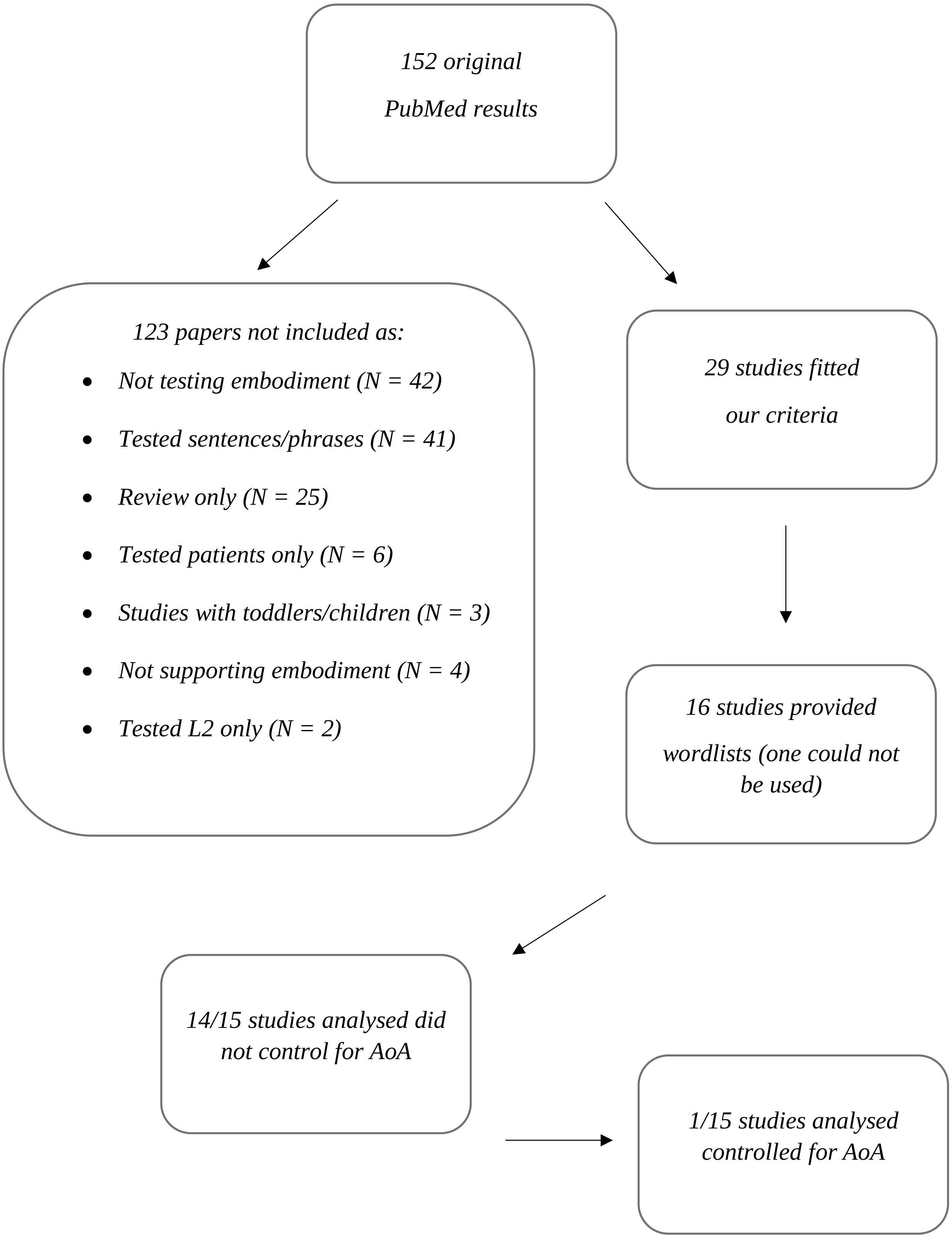


Figure 4.1. *Results from the PubMed search and reasons for exclusions.*

4.2.2 AoA results

After establishing AoA norms for each available stimulus set, the desired analysis was performed. Here, we divided wordlist/s into the same categories/factors that were tested in each study, whereas now we included AoA value as the dependent variable. This analysis, as shown in Table 4.1, found that 6/14 studies that had not considered AoA could have been influenced by the variable. Moreover, the findings were spread throughout behavioural, neuroimaging, and brain stimulation studies. For example, a behavioural experiment (i.e., an LDT) by Dreyer et al. (2015) tested patients and controls as they processed tool, food, animal, and abstract emotional nouns in addition to hand, face, leg, and abstract verbs. For nouns, the results showed that control participants had significantly longer RTs while tool nouns and abstract emotional nouns were processed. In relation to verb processing, hand-related verbs elicited significantly quicker hand RTs relative to the other verb categories. Our analysis established an AoA norm for each word. A between-groups ANOVA then compared the four noun categories using AoA value as the outcome variable; here, a significant main effect was found F (3, 141) = 21.9, $p < .001$, $\eta^2 = .31$), suggesting that the finding could have resulted from AoA. The same process was applied to the different verb types; this analysis also revealed a significant main effect (F (3, 155) = 5.4, $p < .002$, $\eta^2 = .10$).

The AoA findings also applied to the fMRI studies in the review. For instance, van Dam et al. (2010) conducted an fMRI study which examined the neural activity of participants who read verbs describing basic hand actions (e.g., *to clean*), specific hand actions (e.g., *to wipe*), and abstract actions (e.g., *to judge*). The experiment found that relative to abstract verbs, both hand-related verb types elicited greater activity in areas such as bilateral inferior frontal lobule (IFL) and bilateral postcentral gyrus. Our analysis then tested whether or not this finding could have been due to AoA. Accordingly, the same three word groups were compared, but AoA value for each word was treated as the outcome variable. Here, a significant main effect was found (*F* (1, 78) = 140.2, $p < 0.001$, $\eta^2 = 0.64$), which suggests that the difference in brain activity could reflect the influence of AoA (early $M = 5.7$, late $M = 8.8$).

AoA findings also extended to brain stimulation studies. For instance, participants in a Gough et al. (2012) study were presented with hand-related and non-hand related natural and artefact nouns – 150 ms after the left hemisphere primary motor cortex was stimulated via TMS. MEPs were then examined from the first dorsal interosseous (FDI) muscle in participants` right hand, which is associated with grasping actions. The results showed significantly greater MEPs while nouns referring to tools were processed (Gough et al., 2012). Our analysis established an AoA norm for each word in the four categories, and a between-groups ANOVA was then conducted with AoA as a dependent variable. This analysis revealed a significant main effect (*F* (3, 30) = 7.3, $p = <.001$, $\eta^2 = 0.42$) – words in the data set differed via whether they were learned early or late, which could have driven the effect. All other effects are reported in Table 4.1. and Appendix C.

Table 4.1

List of studies reviewed and AoA result for each

Authors	**Task**	**Dependent measure**	**Language**	**Methods**	**Words tested**	**Our contrasts/ Potential effect of AoA**
Sokoliuk et al. (2019)	Read bodily action and non-bodily action words	ERPs during noun and verb processing	English	EEG, RTs to catch trials only	Verbs	No, AoA was controlled
Moseley & Pulvermüller (2014)	Read abstract/ concrete nouns & verbs	Neural areas involved in noun and verb processing	English	fMRI	Verbs	Concrete Nouns vs. verbs: $p < 0.001$
Mollo et al. (2016)	Semantic decision (SDT) and lexical decision task (LDT)	Neural areas involved in verb processing. Hand and foot response times (RTs) to real (LDT) and concrete words (SDT)	English	EEG, RTs	Verbs	Hand vs. foot verbs $p = 0.46$
Kemmerer et al. (2008)	SDTs	Neural areas involved during verb processing. Hand RTs to most semanticall y similar verb or wingding	English	fMRI, RTs	Verbs	Between all 5 verb classes: $p = 0.57$
Miller et al. (2018) Exps. 1, 3, 4, 5	SDT LDT Stroop Memory task	ERPs during hand/foot related verb trials. RTs to verbs.	English	EEG, RTs	Verbs	Exps. 1+3 – Hand vs. foot verbs: $p = 0.11$ Exp.4 – hand vs foot verbs: $p = 0.25$

						Exp.5: hand vs foot verbs: *p* = 0.11
Zhang et al. (2016)	SDT	Hand and foot RTs to hand- and foot-related nouns and pictures	English	RTs	Nouns	Hand vs. foot nouns: *p* = 0.9
Buccino et al. (2018)	SDT	Hand RTs to real nouns and pictures of objects	Italian (Not enough values, so Kuperman et al. norms used)	RTs	Nouns	Hand vs. non-hand nouns: *p* = 0.36
Gough et al. (2012)	Read hand-related, non-hand related, natural, artefact nouns	Motor evoked potentials (MEPs) from grasping/ releasing muscles in arm	Italian (Not enough values, so Kuperman et al. norms used)	TMS, RTs to catch trials only	Nouns	Between four noun types: *p* < 0.001
Dreyer & Pulvermüller (2018)	Read abstract emotional, mental, food, tool nouns	Neural basis of noun processing	German (Not enough values, so Kuperman et al. norms used)	fMRI	Nouns	Between four noun types = *p* < 0.001
Dreyer et al. (2015)	LDT	Hand RTs to food, animal, tools, and abstract-emotional nouns and to face, hand, leg and abstract verbs	German (Not enough values, so Kuperman et al. norms used)	RTs	Nouns and verbs	Between four noun types = *p* < 0.001 Between four verb types = *p* < 0.002
Dreyer et al. (2020)	LDT	Voxel-wise analysis during	German (Not enough	MRI, RTs	Nouns	Three noun types: *p* < 0.70

		processing of and hand RTs to food, animal, tool nouns	values, so Kuperman et al. norms used)			
Willems et al. (2010)	LDT and imagery task and examine overlapping neural activity	Neural basis of manual and non-manual verb processing	Dutch	fMRI, RTs to catch trials only	Verbs	Manual vs. non-manual verbs: *p* = 0.25
Willems et al. (2010) *Note, same stimuli as above*	LDT and imagery task and examine overlapping neural activity	Neural basis of manual and non-manual verb processing in left vs. right handers	Dutch	fMRI, RTs to catch trials only	Verbs	Manual vs. non-manual verbs: *p* = 0.25
van Dam et al. (2010)	SDT	Neural basis of abstract, basic hand, specific hand verbs	Dutch	fMRI, RTs to catch trials only	Verbs	Basic + specific vs. abstract verbs: *p* < 0.001 Basic vs. specific verbs: *p* = 0.60
van Dam et al. (2012)	SDT	Neural basis of action-colour and abstract verbs	Dutch	fMRI, RTs to catch trials only	Verbs	Action colour vs. abstract verbs: *p* < 0.001

4.3 Discussion

This chapter examined the potential influence of *age of acquisition* (AoA) on effects consistent with the embodiment of language. Specifically, we conducted a review and an analysis of previous language embodiment findings to determine whether or not AoA could have been a confounding factor. Accordingly, we searched the *PubMed* database for language embodiment studies – that were conducted between 2000-2022 – that tested motor responses (with any body part) and/or cortical motor activity while either single verbs, nouns, adjectives, or adverbs were processed. We then established whether or not these studies had controlled for AoA as a variable; here, we found that only 1/15 studies that suited our review (had considered AoA, whereas the other 14/15 did not. Next, an AoA value was established for each word in the 14 studies (typically based upon Kuperman et al `s 2012 norms), and we tested whether or not AoA could have been a potential influencing factor. Explicitly, to further ascertain the potential impact of AoA, we tested the same categories/contrasts that were examined in each study, but we included AoA value as a dependent variable. This analysis found some interesting results.

Overall, as discussed, of the 15 studies reviewed, only one had controlled for AoA – Sokoliuk et al. (2019). Thus, the majority of embodiment research that we reviewed over a 22-year period had not considered the potential impact that AoA might have. Additionally, our subsequent analysis showed that 6/14 studies (i.e., approx. 40%) that had not considered AoA could have been impacted by the omission – given that the word categories compared in these studies were influenced by significant differences between early learned vs. late learned words. Thus, the effects described in these studies could actually reflect early vs. late learned word differences. All things considered, this implies that many existing embodiment findings could have been intertwined with AoA, and the variable could have been a potential confound in previous language embodiment research.

To avoid such issues in future work, language embodiment researchers should aim to consider AoA as a factor and group words accordingly. This would eliminate the potential influence of AoA as a variable and arguably provide a more accurate representation of hand-related and non-hand related words` effects. However, controlling for AoA raises some interesting issues, as it is not such a simple task. For example, currently, there is no agreed method to measure AoA, and typically, researchers use adult participants` subjective estimates of when a word was learned (i.e., Navarrete et al., 2015; Stadthagen-Gonzalez et al., 2004). There are potential issues with this method, though; for example, subjective ratings tend to be influenced by factors such as word length and frequency, as easier recalled words tend to be shorter and more frequent and thus judged as learned earlier (Brysbaert & Biemiller, 2017). Accordingly, some groups have tried to construct more objective norms by successfully correlating their own subjectively collected adults` estimates to other groups` ratings (see Brysbaert & Biemiller, 2017; Kuperman et al, 2012). Both Brysbaert and Biemiller (2017) and Kuperman et al. (2012) have gone further by also comparing their subjective ratings to data from the online *English Lexicon Project*, which is a US database containing RTs to over 40,000 words and non-words (Balota et al., 2007). Here, Kuperman et al. (2012) found that their collected AoA ratings had the second highest overall correlation with RT data (after word frequency) and predicted a linear increase in RT speed for each year. Later, Brysbaert and Biemiller (2017) showed that the Kuperman et al. (2012) norms were more strongly correlated to RT data than frequently used test-based norms (i.e., Dale & O'Rourke, 1981). Taken together, it could be argued that the Kuperman et al. (2012) norms are as close to objective as is currently available; however, there are further issues pertaining to using these norms.

For example, the primary researcher for this thesis lives and works in Ireland, and it is quite plausible that there are words that are well known there (and early learned) that are less known elsewhere and/or are used in a different context. For example, *hurling* is Ireland`s national sport, and it is played by thousands of young people (from approximately 5/6 years old +) and adults throughout the island (GAA, 2015). Consequently, words associated with the game of hurling (e.g., *sliotar*, *hurl*, *puck*) would be quite familiar to many in Ireland (and in some small sections of the UK and the USA) and would be learned quite early, too. These words may not be so familiar to those outside of Ireland, and some could be learned within a completely different context and at a later stage. For instance, on the Kuperman et al. (2012) AoA database, the word *hurl* is defined as to "throw", and it is estimated that it is learned at approximately 8.2 years old. However, in Ireland, to many, a *hurl* refers to the stick used to play hurling (i.e., an object) and/or to the act of hurling itself (e.g., he used to *hurl* with our team). This highlights the potential impact that culture could have on the processing of different words, and it also shows how words that are spelled the same way can mean very different things. Thus, language acquisition in one country can differ to the next, and that which is learned early may be learned later or in a different context in another country. Accordingly, all norms on the Kuperman et al. database may not be suitable for all English language experiments in all countries.

Furthermore, while research groups like Brysbaert and Biemiller (2017) and Kuperman et al. (2012) have tried to construct large databases of norms, there are considerably more English words than the 40,000+ typically contained in these databases. For example, the Oxford English dictionary estimated that there are over 170,000 base form words currently in use and over 600,000 English words in their databases (OED, 2022). Constructing norms for all English words is thus almost impossible, and potentially, some of the words in the Oxford database could be culturally specific, too. All in all, these factors highlight some of the issues related to controlling for AoA in English language experiments. Additionally, our review found that the number of non-English norms is much fewer than those constructed in English. From an international perspective, this further emphasises the difficulty controlling for AoA.

Still, our work here does imply that many previous embodiment effects may have differed if AoA was considered as a variable – which calls into question some of the claims from previous researchers (including one of our group – Gough et al. 2012) and warrants caution for future language embodiment research. As such, some effort should be made to try to control for AoA in future to remove its potential as a confound, which, as discussed, has been attempted by some. Certainly, for studies that aim to use English words, the Kuperman et al. (2012) norms provide a reasonable option. Researchers could also collect separate adults` ratings and compare these to the database norms. Alternatively, language researchers could use words from relevant early and later schoolbooks or ask school teachers to rate lists of words as early or late learned. This would allow for a potentially more objective measure of AoA ratings and allow researchers to plan accordingly. The next chapter in this thesis will examine the impact of AoA more directly by testing its real-time effect on hand responses and how it interacts with factors like word frequency and hand relatedness. This should enable us to know more about the topic of AoA overall and to further ascertain its influence in language embodiment research.

Overall, the current chapter tested the potential effect of *age of acquisition* (AoA) on previous embodiment research and found that many previous studies` findings could have been confounded by AoA. Consequently, future research should try to account for this variable and group words accordingly. However, as discussed, this process presents certain issues, and researchers should keep these in mind. Disentangling AoA effects from embodiment research will prove extremely beneficial, though, as it would allow researchers to gain a greater overall understanding of the topic and remove the potential influence of AoA as a confounding variable.

Chapter 5

Age of Acquisition and The Embodiment of Language

Abstract

Embodiment of language theories propose that language and action are inter-related. *Age of Acquisition* (AoA) effects refer to the findings that words, phrases, and concepts learned early in life are processed quicker than stimuli learned later in life (Brysbaert et al., 2000). However, as highlighted in Chapter 4, AoA is a factor that is often not considered in embodiment studies; thus, the influence of AoA on motor responses is not entirely clear. Accordingly, using two different samples (younger adults aged 18-44, N = 40; and older adults aged 50-65, N = 40), the current experiments tested the effect of AoA on motor responses to language. Participants in both groups undertook a lexical decision task (LDT). With the younger sample, the results showed a significant interaction effect between AoA and Hand Relatedness – hand-related stimuli learned early in life (early AoA) elicited quicker hand responses than non-hand related stimuli learned early in life. However, hand-related stimuli learned late in life (late AoA) elicited slower hand responses than non-hand related stimuli learned late in life – suggesting that embodied effects may only apply to early learned language. The older adult experiment found no effect for hand-related stimuli when AoA was controlled, which suggests that embodied effects could also be related to age. The implications of these findings for language embodiment theories are discussed within.

5.1 Introduction

Theories of language embodiment are typified by the claim that language and action are inter-related. At the crux of this claim is the proposition that processing language is built upon experiences of the actions, objects, and events to which the language refers (Barsalou, 1999; Buccino et al., 2005; Gallese, 2008; Gough et al., 2013; Marino et al., 2011; Pulvermüller, 2005). Support for the embodiment of language has come from studies which have found that processing words referring to bodily actions (i.e., verbs) activates and uses the same motor areas that underpin the production of the bodily actions (see Andres et al., 2015; Boulenger et al., 2006; Buccino et al., 2005; Gianelli et al., 2020; Gough et al., 2013; Hauk et al., 2004; Mirabella et al., 2012; Repetto et al., 2013; Van Dam et al., 2010). For example, using functional magnetic resonance imaging (fMRI), Van Dam et al. (2010) demonstrated that processing verbs referring to specific hand actions (e.g., *to cut*) activated the inferior parietal lobule (IPL) to a greater degree than during the processing of verbs describing general hand actions (e.g., *to attach*) and abstract verbs (e.g., *to wish*), respectively. Given that the IPL is known to be involved in coding for specific grasping actions, the findings suggest that the neural representation of the verb is closely related to the action described (Van Dam et al., 2010). Additionally, numerous behavioural experiments have shown that processing verbs related to specific body parts (i.e., the hand –*grab*; or the foot – *kick*) can modulate responses (RTs) performed with the corresponding body part (i.e., the hand or the foot – see Buccino et al., 2005; Boulenger et al., 2006; Mirabella et al., 2012; Repetto et al., 2013; Andres et al., 2015; Gianelli et al., 2020). These findings also imply a strong link between the word and the representation of the action conveyed in the word.

Further support for embodiment of language theories has come from studies which have shown that processing nouns describing objects upon which the body can act also activates and uses the motor areas involved in the corresponding act (see Buccino et al., 2018; Gough et al., 2012; Kuhnke et al., 2020; Marino et al., 2011; 2014; Zhang et al., 2016). For instance, Kuhnke et al. (2020) showed that processing nouns associated with sounds (e.g., *tuba*) and actions (e.g., *pliers*) activated the neural areas involved in auditory and motor tasks, respectively. As with verb processing, many behavioural studies have also shown that processing nouns referring to graspable/hand-related objects (e.g., *pencil*) can modulate subsequent hand RTs (e.g., Buccino et al., 2018; Marino et al., 2011, 2014; Zhang et al. (2016) – again, suggesting that the neural representation of nouns is closely related to the object described by the noun. Taken together, studies on verb and noun processing (and adjectives - see Garofalo et al., 2021; Gough et al., 2013) suggest that language and action are interrelated and that processing language is an embodied process.

Age of Acquisition (AoA) refers to the period within which a word, phrase, skill, or concept has been learned (Brysbaert et al., 2000; Catling & Elsherif., 2020; Ellis et al., 2010). Typically, early AoA reflects the period before aged 6/7 years old, while late AoA reflects the period after aged 6/7 years old. Moreover, in a range of experimental tasks, early AoA has been shown to have an RT advantage over late AoA (see Arnon et al., 2017; Brysbaert et al., 2000; Catling et al., 2013; Ellis et al., 2010; Morrison & Ellis, 1995; Stadthagen-Gonzalez et al., 2004), and these effects have also been shown to persist across the lifespan. For instance, a Catling et al. (2013) study compared object naming (via pointing) in younger controls (aged 20-26 years old), healthy controls (aged 75-86 years old), and older adults with cognitive impairments (aged 77-87 years old). Across all three groups, early learned items elicited quicker verbal responses than late learned items, though response times did decrease with age and with impairment. In a later study by Navarrete et al. (2015), a similar early AoA advantage was found in relation to speech production. Additionally, in two separate studies, Cuetos et al. (2010; 2017) found that Alzheimer`s Disease (AD) patients were better able to remember and point to early learned words than late learned words – even though the AD group were significantly more impaired than controls. Overall, these findings highlight the influence that early learned items have over late learned items across the lifespan and even suggest that AoA could be a potential mediator for cognitive decline.

Thus, AoA is a factor that tends to have an influence on responses across many different types of tasks. However, our previous chapter (see Chapter 4) found that the majority of language embodiment studies that were reviewed (i.e., 14/15) had not considered AoA as a factor. Further analysis found that 6/14 of these studies` findings could have been influenced by AoA – further highlighting its importance as a variable. The present experiments further explored this importance by directly examining *the effect of AoA on the embodiment of language*. Specifically, we tested the effect of hand-related stimuli on hand RTs (our measure of embodiment) whilst accounting for AoA as a variable. We also tested how AoA interacted with word frequency and how both factors interacted with the embodiment of language.

To understand more about the interaction between AoA and hand-related stimuli, a lexical decision task (LDT) was first presented to a sample of younger participants (i.e., 18-44 years old); the task required a hand response to real words and no response to pseudo words. Though not explicitly required for performance, this task is thought to access semantic representations (e.g., Dreyer et al., 2015; Neininger & Pulvermüller, 2003). Half the real words were hand related, and half were non-hand related, and within these categories, half were early acquired (i.e., learned before aged 6/7) and half were late acquired (i.e., learned after aged 6/7). Additionally, half the words were high in frequency, and half were low in frequency. The experiment tested for main effects of each factor (i.e., Hand Relatedness, AoA, and Frequency) and for interaction effects between all factors. Overall, early acquired words were expected to elicit quicker hand RTs than late acquired words, and high-frequency words to elicit quicker hand RTs than low-frequency words. Of particular interest was whether or not the expected main effect for Hand Relatedness (i.e., different hand RTs to hand-related words), if present, was being driven by early learned, hand-related words. This analysis allowed us to establish whether or not language embodiment effects persisted when AoA was controlled.

The same LDT was then presented to an older adult sample (i.e., aged 50-65 years old). Here, in line with previous studies (see earlier sections), we expected the advantage for early learned words to persist – given the strength of AoA as a variable and given that language processing abilities have been shown to remain relatively spared across the lifespan (see Grieder et al., 2012; Shafto & Tyler, 2014; Tiedt et al., 2020). However, the potential impact of hand-related stimuli on older adults` processing and how this would interact with AoA was a little less clear. Recently, a Reifegerste et al. (2021) conducted a study which compared verb and noun processing in different younger and older samples – also using LDTs. Here, in two of the LDTs, it was found that older adults` (generally, aged 60-76 years old) hand RTs were significantly impaired during the processing of non-hand related words only (Reifegerste et al., 2021). In the second LDT, with different groups, both hand-related and non-hand related words elicited significantly slower RTs in the older group, though the effect for the non-hand related words was larger. Their other experiment – a picture naming paradigm –also found a significant association between increased age and processing non-hand related words. Taken together, these findings suggest that processing hand-related stimuli can still elicit typical hand RT effects with older age groups, though there are others who have posited that older adults are less embodied overall and more dependent upon visual clues (e.g., Costello et al., 2017) and impaired on LDTs compared to younger adults (e.g., Gold et al., 2009). The second experiment in this chapter allowed us to further test these claims and to understand more about language representation in older and younger groups.

Lexical decision task – younger adults

5.1.1 Method

5.1.1.1 Participants

A total of 40 participants were recruited for the experiment (20 females and 20 males – no other genders were reported), all of whom were aged between 18 and 44 years (*M* = 22.3, *SD* = 6.2). All were recruited via a poster advertisement in Maynooth University (MU) and from a research participant pool in MU University`s Department of Psychology. Those who were recruited from the participant pool received course credit for their participation. All participants were right-handed according to the Edinburgh Handedness Inventory Form (*M* = 73.9, *SD* = 14.9) (Oldfield, 1971) and spoke English as a first language. No participant had issues with psychological/neurological impairment; history of epilepsy or memory issues; or history of language related disorders (e.g., dyslexia, aphasia). No financial incentives were offered for participation. The experiment was conducted in accordance with MU`s research policy and received approval from MU Social Research Ethics Sub-Committee (SRESC-2018-144).

5.1.1.2 Stimuli

The stimuli consisted of 120 English words and 60 pseudowords. The 120 English words were comprised of 30 verbs and 30 nouns that are learned before the age of 7 years old (i.e., early acquired – as per Brysbaert & Ghyselinck, 2006; Kogan et al., 2020) and 30 verbs and 30 nouns that are learned after 7 years old (i.e., late acquired). The early acquired words were drawn from the *Jolly Phonics* series of workbooks and activity books – designed to be taught to school children who are approximately 4-6/7 years old (Lloyd, Wernham & Stephen, 2018). The late acquired words were taken from the *Less Stress More Success* English book (Kelly, 2018) and from the *English Extra* revision book (Behan, 2019) – both of which apply to older students in

Ireland (i.e., 16-18/19 years old). Half the verbs and nouns in both the early and late acquired conditions were hand related (e.g., *coat, strike*), and the other half were non-hand related (e.g., *garage, vary*) – as agreed by the three researchers involved in the experiment. Additionally, half the words in both the early and late acquired conditions were high in frequency, while the other half were low in frequency. High in frequency was defined as having a combined total of 150 + from the Thorndike-Lorge written frequency (1944) and Kucera-Francis written frequency scales, as per the MRC Psycholinguistic Database (Coltheart, 1981). Low in frequency was defined as scoring a total of < 150 on the same two psycholinguistic scales. Thus, overall, each presented word was comprised within the categories of AoA (early/late acquired), Hand Relatedness (hand related/non-hand related), and Frequency (high/low) (see Appendix D).

AoA and Hand Relatedness stimuli were also balanced for various psycholinguistic variables using the MRC Psycholinguistic Database (Coltheart, 1981). Firstly, written frequency was assessed on the Kucera-Francis (1967) written frequency scale. Here, there was no significant main effect for AoA (i.e., no significant differences in frequency between early and late acquired words (F (1, 106) = 0.01, p = 0.9) or Hand Relatedness (i.e., no significant differences in frequency between hand-related and non-hand related words (F (1, 106) = 0.97, p = 0.33). There was a significant main effect for frequency, as manipulated by the experiment (i.e., difference in frequency between high and low frequency words (F (1, 106) = 15.94, p = 0.001). There were no significant interaction effects between AoA and Hand Relatedness (F (1, 106) = 1.23, p = 0.27); AoA and Frequency (F (1, 106) = 0.57, p = 0.81); Hand Relatedness and Frequency (F (1, 106) = 0.69, p = 0.40); or AoA, Hand Relatedness, and Frequency (F (1, 106) = 1.29, p = 0.26).

Secondly, we assessed written frequency via the Thorndike-Lorge written frequency scale. Here, there was no significant main effect for AoA (F (1, 111) = 3.28, p = 0.07) or Hand

Relatedness (*F* (1, 111) = 0.31, *p* = 0.57). There was a significant main effect for frequency as manipulated by the experiment (*F* (1, 111) = 79.64, *p* = 0.001). There were no significant interaction effects between AoA and Hand Relatedness (*F* (1, 111) = 0.33, *p* = 0.57); AoA and Frequency (*F* (1, 106) = 1.25, *p* = 0.27); Hand Relatedness and Frequency (*F* (1, 111) = 0.01, *p* = 0.94); or AoA, Hand Relatedness, and Frequency (*F* (1, 111) = 0.56, *p* = 0.45).

Additionally, all stimuli were balanced for number of syllables, with no significant main effect for AoA (*F* (1, 112) = 3.53, *p* = 0.06), Hand Relatedness (*F* (1, 112) = 0.26, *p* = 0.60), or Frequency *F* (1, 112) = 2.36, *p* = 0.12). There were also no significant interaction effects between AoA and Hand Relatedness (*F* (1, 112) = 0.29, *p* = 0.86); AoA and Frequency (*F* (1, 112) = 3.52, *p* = 0.06); Hand Relatedness and Frequency (F (1, 112) = 0.73), *p* = 0.87; or AoA, Hand Relatedness, and Frequency (*F* (1, 112) = 0.01, *p* = 0.87). The 60 pseudowords were created using Microsoft Excel, version 16.0, by randomly ordering the letters that comprised the real English words in the experiment and constructing new pseudo words. The pseudowords and real words were also matched for number of letters.

5.1.1.3 Procedure

All participants were tested individually at MU`s Department of Psychology. Upon arrival, each participant was provided with an information sheet outlining the general nature of the experiment. They were then required to complete the attached consent form before being taken to a dimly lit testing cubicle. Here, the participant sat on a chair approximately 55 cm from a 15-inch standard 4:3 ratio computer screen. The computer screen and keyboard were placed on a small table, just in front of the participant`s chair. The participant was informed that the experiment would consist of a number of onscreen trials, and that each trial would present a string of letters in the centre of the screen. They were instructed to read the letter strings carefully and to respond – by quickly pressing the spacebar on the keyboard with the right hand only – whenever the letter string was a real word. Participants were also instructed to refrain from responding when the letter string was not a real word. The instructions for the experiment were then presented onscreen, and the experimenter ascertained if each participant understood the task. The experiment then began when the participant pressed the spacebar on the computer keyboard.

The experiment was presented via *EPrime* Psychology Software Tools, version 2.0, (2018). All stimuli were presented in the centre of the screen in black Courier New size 32 font, on a silver background. Overall, the experiment consisted of 360 trials (block of 180 stimuli presented twice). Each trial began with a fixation cross that was presented for 1000 ms. A letter string (i.e., a real word or a pseudoword) was then presented for 1000 ms. The participant was required to respond when the letter string was a real word, whereas a pseudoword required no response. A blank screen was then presented for 1000 ms before the experiment moved on to the next trial (see Figure 5.1). Each trial lasted 3000 ms, and all trials took approximately 20-25 minutes to complete. After every 90 trials, participants were allowed to take a break. After each break, the experiment continued when the participant pressed the spacebar. Trials were presented in a randomised order.

5.1.1.4 Design

The experiment used a 2 x 2 x 2 repeated-measures design. The independent variables were AoA (early/late), Hand Relatedness (hand related/non-hand related), and Frequency (high/low). The dependent variable was participants` hand RTs to letter strings that described real words.

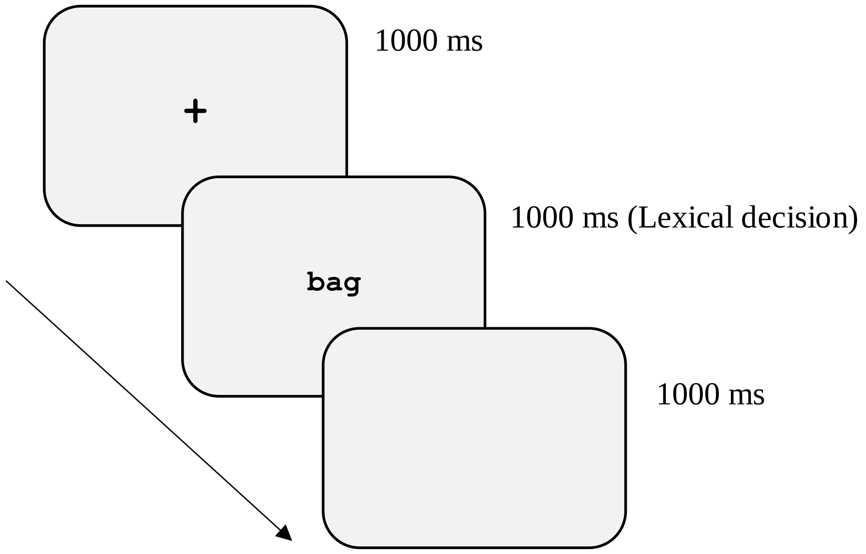


Figure 5.1. Example of a trial from the experiment. Fixation cross appeared for 1000 ms. A letter string (e.g., a real word – *bag* – requiring a response; or a pseudoword – *smoh* – not requiring a response) was then presented for 1000 ms. A blank screen appeared for 1000 ms before the experiment moved on to the next trial.

5.1.1.5 Statistical analyses

A total response accuracy score was calculated for each participant for the 360 trials. This was computed by adding the number of missed responses during the 240 real word trials to the number of incorrect responses during the 120 pseudoword trials. Here, participants had a mean accuracy rate of 98% (Standard Deviation (*SD*) = 1.3) across all trials. No participant`s response accuracy score was below the set threshold of 85% (see Gough et al., 2012), so no participant was excluded from the final analyses. A mean response time (RT) across all trials was then calculated for each of the 40 participants individually, and all individual responses that were 2 *SDs* above or below this mean were excluded from the analyses. On average, 97%

of participants` responses were within 2 *SDs* of their individual mean times, and no participant`s time accuracy score was less than 96%. All preliminary analyses were conducted using Microsoft Excel, version 16.0. Data were then transferred into IBM SPSS, version 25, where a 2 x 2 x 2 repeated-measures ANOVA was performed. The ANOVA tested for main effects of AoA, Hand Relatedness, and Frequency and for interactions between factors. P < 0.05 was taken as significance, and where appropriate, a star-based system displaying significant differences was used on the figures (* $p < 0.05$, ****** $p < 0.01$, and ******* $p < 0.001$).

5.1.2 Results

Mean RTs for each experimental condition were first calculated, and these are highlighted in Table 5.1. Data were entered into the 2 (AoA: early/late) x 2 (Hand Relatedness: hand related/non-hand related) x 2 (Frequency: high/low) repeated-measures ANOVA.

Table 5.1.

Mean RTs and SDs for each experimental condition

Condition	N	Mean	SD	Min	Max
EarlyHandHigh	40	492.0	60.2	400.9	696.7
EarlyHandLow	40	508.0	62.2	421.3	739.9
EarlyNonHandHigh	40	500.4	61.4	394.3	723.8
EarlyNonHandLow	40	511.1	64.5	419.6	752.0
LateHandHigh	40	523.1	64.2	425.5	767.5
LateHandLow	40	525.5	73.2	419.2	795.4
LateNonHandHigh	40	513.6	62.8	427.0	768.6
LateNonHandLow	40	521.5	67.4	421.3	807.2

The ANOVA found a significant main effect for AoA (F (1, 39) = 98.70, $p = 0.001$, $\eta^2 = 0.72$) – RTs during the processing of early acquired words were significantly quicker than RTs while late acquired words were processed (502.8 ms +/- 9.6 and 520.97 ms +/- 10.4, respectively, see Figure 5.2). A significant main effect for Frequency was also found (F (1, 39) = 20.44, $p = 0.001$, $\eta^2 = 0.34$). Here, significantly quicker RTs were observed during the processing of high-frequency words compared to low-frequency words (507.3 ms +/- 9.6 and 516.55 ms +/- 10.4, respectively, see Figure 5.3).

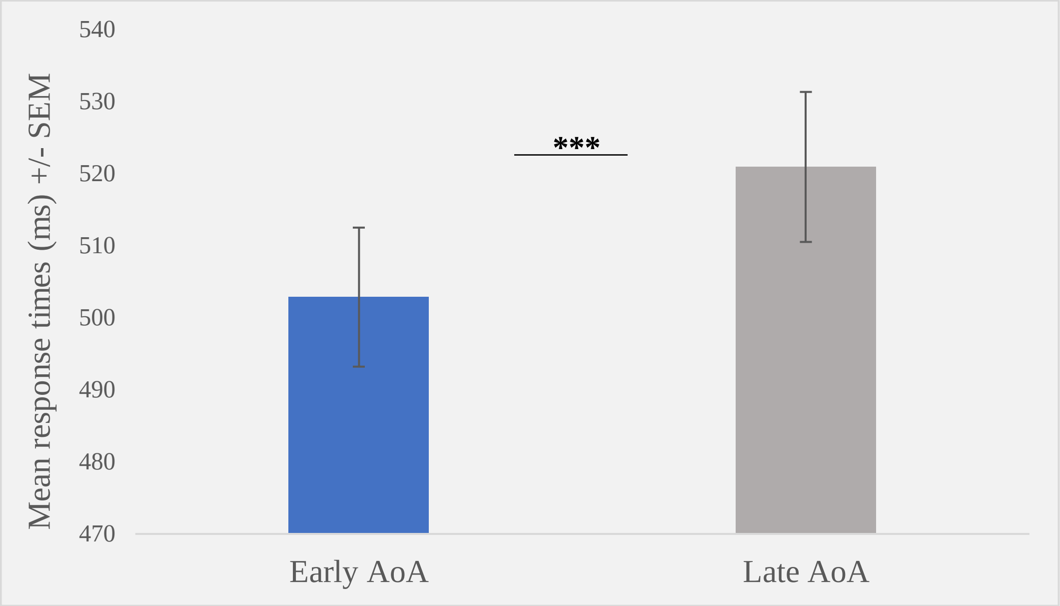


Figure 5.2. Mean RTs while early and late acquired words were processed.

Error bars represent the standard error of the mean (SEM).

*** denotes that *p* = < 0.001.

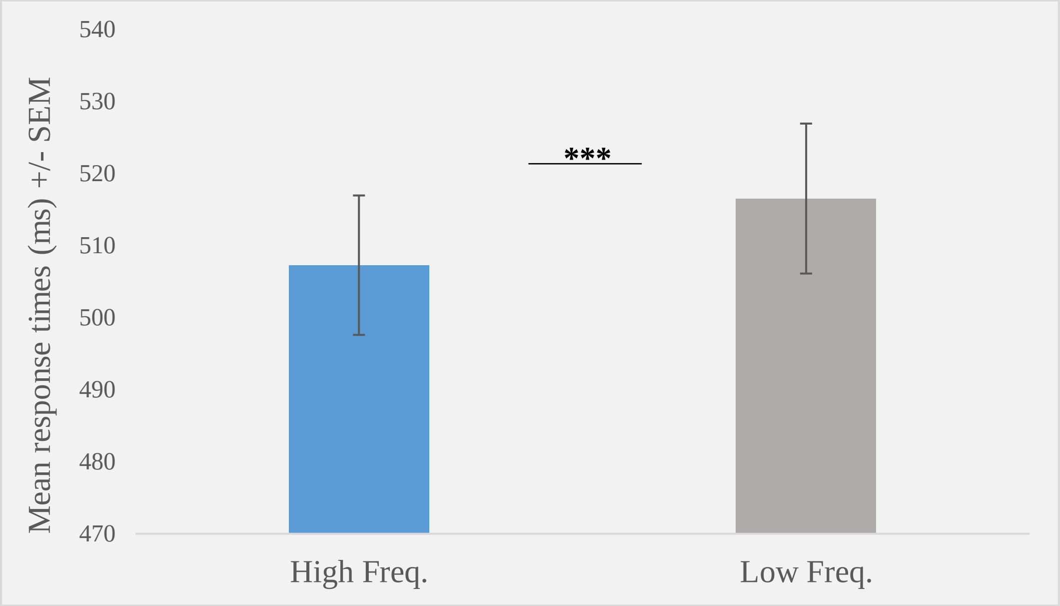


Figure 5.3. Mean RTs while high- and low-frequency words were processed.

Error bars represent the standard error of the mean (SEM).

*** denotes that *p* = < 0.001.

No significant main effect was found for Hand Relatedness (*F* (1, 39) = 0.11, *p* = 0.74.) – RTs during the processing of hand-related words were only marginally slower than RTs during non-hand related word processing (512.1 ms +/- 10.1 and 511.7 ms +/- 9.9, respectively, see Figure 5.4).

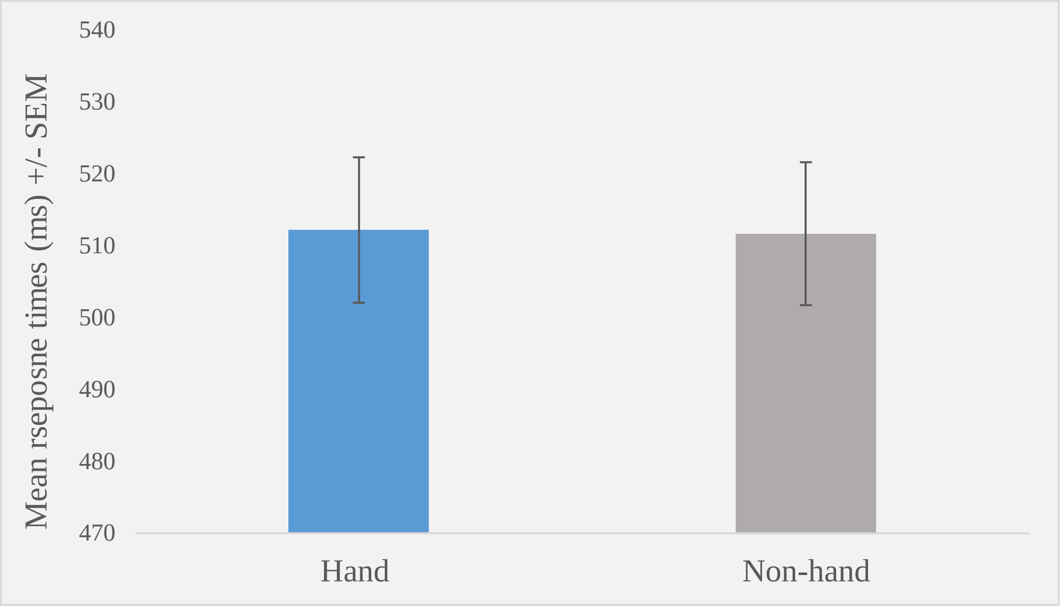


Figure 5.4. Mean RTs while hand-related and non-hand related words were processed. Error bars represent the standard error of the mean (SEM).

No significant interaction effect was found between Hand Relatedness and Frequency (*F* (1, 39) = 0.001, *p* = 0.9) or between AoA, Hand Relatedness, and Frequency (*F*, (1, 39) = 3.32, *p* = 0.07). However, a significant interaction effect was found between AoA and Hand Relatedness (*F* (1, 39) = 25.45, *p* = 0.001, η^2 = 0.4). As highlighted in Figure 5.5, this appears to be due to a difference in the direction of the interaction between early AoA/Hand Relatedness and late AoA/Hand Relatedness. A split-file analysis – which examined early acquired and late acquired words separately – confirmed that the effect of Hand Relatedness on hand RTs was significant for both early AoA and late AoA, but in opposite directions.

Specifically, early acquired, hand-related words elicited significantly quicker hand RTs than early acquired, non-hand related words (*F* (1,39) = 13.06, *p* = 0.001, $\eta^2 = 0.25$) (500.0 ms +/- 9.5 vs. 505.74 ms +/- 9.8, respectively). However, for late AoA, the significant main effect was due to significantly slower RTs while hand-related words were processed vs. non-hand related words (524.34 ms +/- 10.8 and 517.60 ms +/- 10.2, respectively *(F* (1, 39) = 8.82, *p* = 0.005, $\eta^2 = 0.2$).

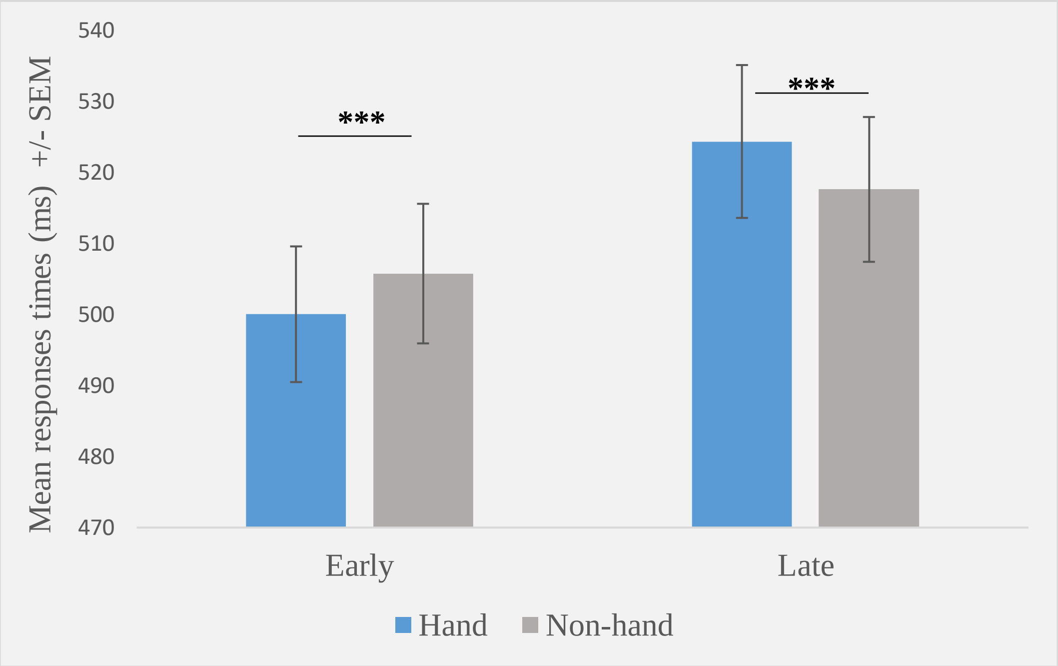


Figure 5.5. Interaction effects between AoA and Hand Relatedness. Error bars represent the standard error of the mean (SEM). *** denotes that *p* = < 0.001.

A significant interaction effect was also found between AoA and Frequency (*F* (1, 39) = 8.13, *p* = 0.007, $\eta^2 = 0.2$). As suggested in Figure 5.6, this is possibly due to a difference in the effect between early AoA/Frequency and late AoA/Frequency – which our split-file analysis also confirmed. Here, a large significant main effect for Frequency was found in relation to early AoA (*F* (1, 39) = 32.24, *p* = 0.0001, $\eta^2 = 0.5$) – RTs were significantly quicker while high-frequency words were processed in comparison to low-frequency words (496.21

ms +/- 9.5 and 509.56 ms +/- 9.9 respectively). However, there was only a trend towards a significant main effect for Frequency in the late AoA conditions (*F* (1, 39) = 3.8, *p* = 0.059), driven by quicker RTs to high-frequency words (518.4 ms +/- 9.9) vs. low-frequency words (523.54 ms +/- 11.0). No significant interaction effects were found between Hand Relatedness and Frequency while early AoA or late AoA words were processed.

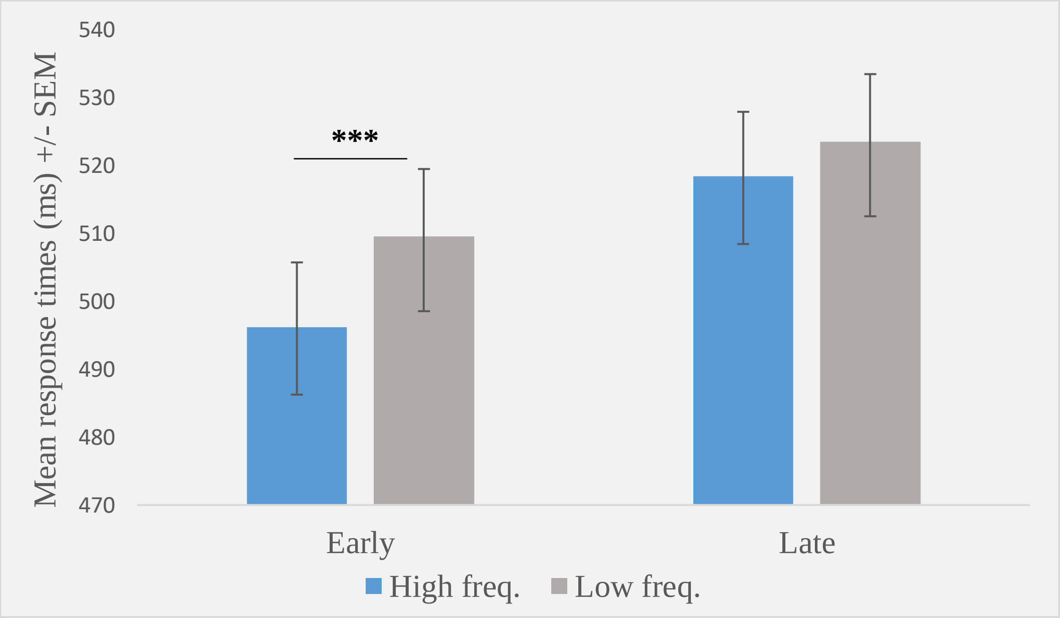


Figure 5.6. Interaction effects between AoA and Frequency. Error bars represent the standard error of the mean (SEM). *** denotes that *p* = < 0.001.

5.2 Lexical decision task – older adults

5.2.1 Method

5.2.1.1 Participants

A total of 40 participants were recruited for the older adult experiment (12 females and 28 males – no other genders were reported), all of whom were aged between 50 and 65 years (*M* = 56.2, *SD* = 4.7). All were recruited via a poster advertisement in MU (MU), via *LinkedIn*, and via the psychology subpages on *Reddit*. According to self-reports, all participants were right-handed and spoke English as a first language. No participant had issues with psychological/neurological impairment; history of epilepsy or memory issues; history of language related disorders (e.g., dyslexia, aphasia) or motor-related issues. No financial incentives were offered for participation. The experiment was conducted in accordance with MU`s research policy and approved by MU Social Research Ethics Sub-Committee (SRESC-2021-2450172). Due to |Covid-19 in-person restrictions in Ireland at the time of testing (i.e., August/September 2021), this experiment was run online.

5.2.1.2 Stimuli

The stimuli consisted of the same 120 English words and 60 pseudowords that were used in the earlier LDT with younger participants. The stimuli used in this experiment were also balanced for the same psycholinguistic variables as before.

5.2.1.3 Procedure

Participants who contacted the researcher through the poster advertisement were emailed a link to the experiment. Separately, the same link to the experiment was posted on *LinkedIn* and the psychology subpages on *Reddit*. Once the participant clicked on the link, they were brought to an information page on *Qualtrics*. The information page provided some basic details about the experiment and collected demographic information such as age, gender and handedness, as well as each participant`s consent. Participants were also asked to tick a box indicating whether or not they had motor-related issues; no participant reported any issues here. If the participant consented, via clicking a link, they were brought to the experiment on *Pavlovia.* Here, the participant was informed that the experiment would consist of a number of onscreen trials, and that each trial would present a blue/lilac letter string in the centre of the screen. Further, they were instructed to read the letter strings carefully and to respond – by quickly pressing the spacebar on the keyboard with the right hand only – whenever the blue/lilac letter string was a real word. They were also instructed to refrain from responding when the blue/lilac letter string was not a real word. Once the participant pressed the spacebar on the computer keyboard, the experiment began.

As with the younger participants, all stimuli were presented in the centre of the screen, on a silver background. However, the older adult LDT was constructed on *PsychoPy* builder (version v2021.2.3) and sent to *Pavlovia* – a software system for running experiments online (see Chapter 2 for a review of both). As font colourings differ between PsychoPy and *EPrime*, the letter string presented here was in blue/lilac Courier New font. The letter height was 0.05, which means that all stimuli would appear as 1/20th the size of each participant's screen. As this experiment was being run online and with older adults, it was decided to only run one block. Thus, in total, the experiment consisted of 180 trials, and all trials were run in the exact same way as with the younger group (see Figure 5.7).

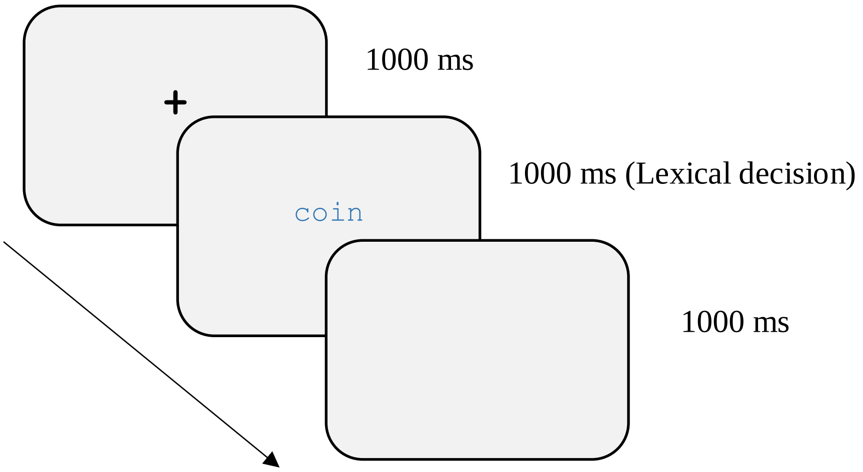


Figure 5.7. Example of a trial from the older adult experiment. Fixation cross appeared for 1000 ms. A letter string (e.g., a real word – *coin* – requiring a response; or a pseudoword – *smoh* – not requiring a response) was then presented for 1000 ms. A blank screen appeared for 1000 ms before the experiment moved on to the next trial.

5.2.1.4 Design and statistical analyses

The older LDT experiment utilised the same 2 x 2 x 2 repeated-measures design as was used with the younger participants. Data were analysed using the same processes as with the younger group. Here, participants had a mean accuracy rate of 99% (Standard Deviation (*SD*) = 1.6) across all trials. No participant`s response accuracy score was below the set threshold of 85% (see Gough et al., 2012), so no participant was excluded from the final analyses. On average, 96% of the older participants` responses were within 2 *SDs* of their individual mean times, and no participant`s time accuracy score was less than 93%.

5.2.2 Results

Mean RTs for each experimental condition were first calculated; these are highlighted in Table 5.2. Data were entered into the 2 (AoA: early/late) x 2 (Hand Relatedness: hand related/non-hand related) x 2 (Frequency: high/low) repeated-measures ANOVA.

Table 5.2

Mean RTs and SDs (ms) for each experimental condition

Condition	N	Mean	SD	Min	Max
EarlyHandHigh	40	560.8	58.6	449.6	687.7
EarlyHandLow	40	573.4	57.6	454.3	689.5
EarlyNonHandHigh	40	564.4	56.6	441.6	684.5
EarlyNonHandLow	40	578.4	57.8	440.5	682.9
LateHandHigh	40	587.1	63.4	456.2	732.8
LateHandLow	40	597.4	65.9	466.9	747.6
LateNonHandHigh	40	576.2	57.1	452.7	724.3
LateNonHandLow	40	603.7	68.0	461.9	769.2

A significant main effect for AoA was found (F (1, 39) = 37.1, p = 0.001, $\eta^2 = 0.5$) – RTs during the processing of early acquired words were significantly quicker than RTs during trials where late acquired words were processed (569.2 ms vs. 591.1 ms – see Figure 5.8). A significant main effect for Frequency was also found (F (1, 39) = 46.7, p = 0.001, $\eta^2 = 0.55$). Here, significantly quicker RTs were observed during the processing high frequency words compared to low-frequency words (572.1 ms and 588.2 ms, respectively – see Figure 5.9).

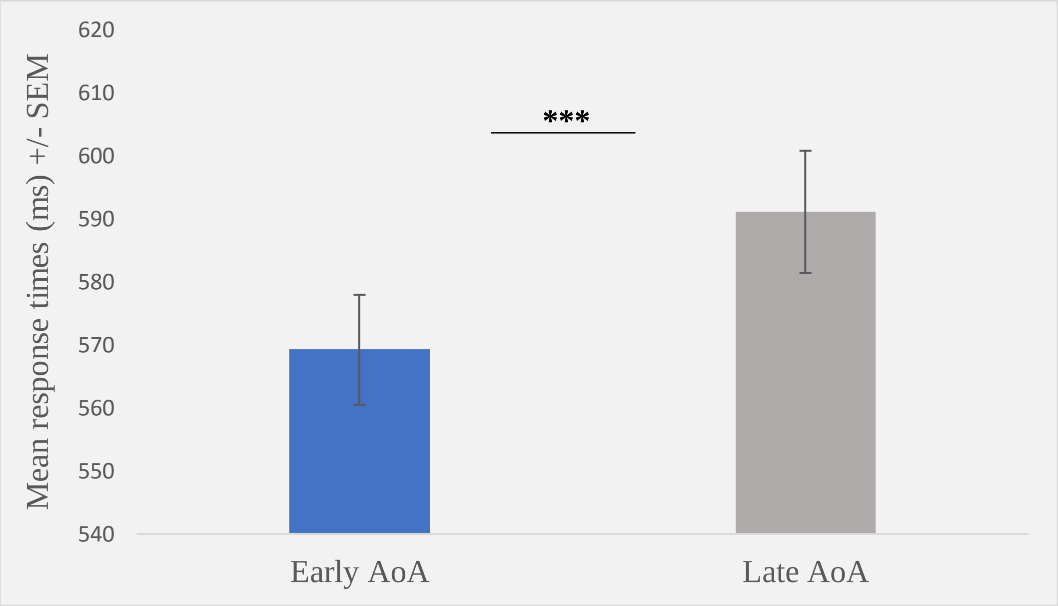


Figure 5.8. Mean RTs while early and late acquired words were processed. Error bars represent the standard error of the mean (SEM). *** denotes that *p* = < 0.001.

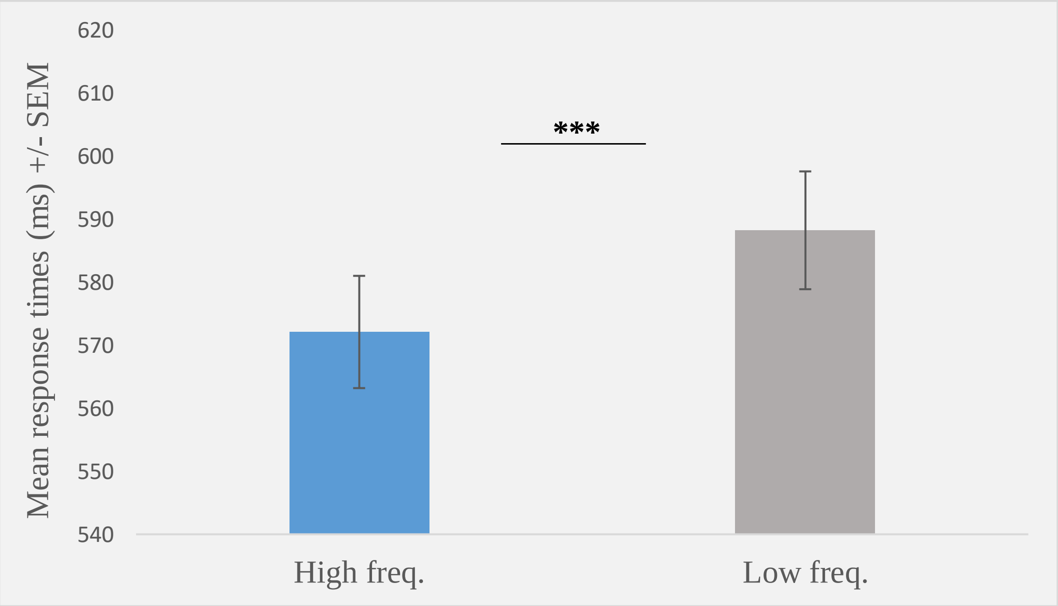


Figure 5.9. Mean RTs while early and late acquired words were processed. Error bars represent the standard error of the mean (SEM). *** denotes that *p* = < 0.001.

No significant main effect for Hand Relatedness was found (F (1, 39) = 0.42, p = 0.52) – RTs during trials with hand-related words were only marginally slower than RTs during non-hand related word trials (579.7 ms vs. 580.7 ms, respectively, see Figure 5.10).

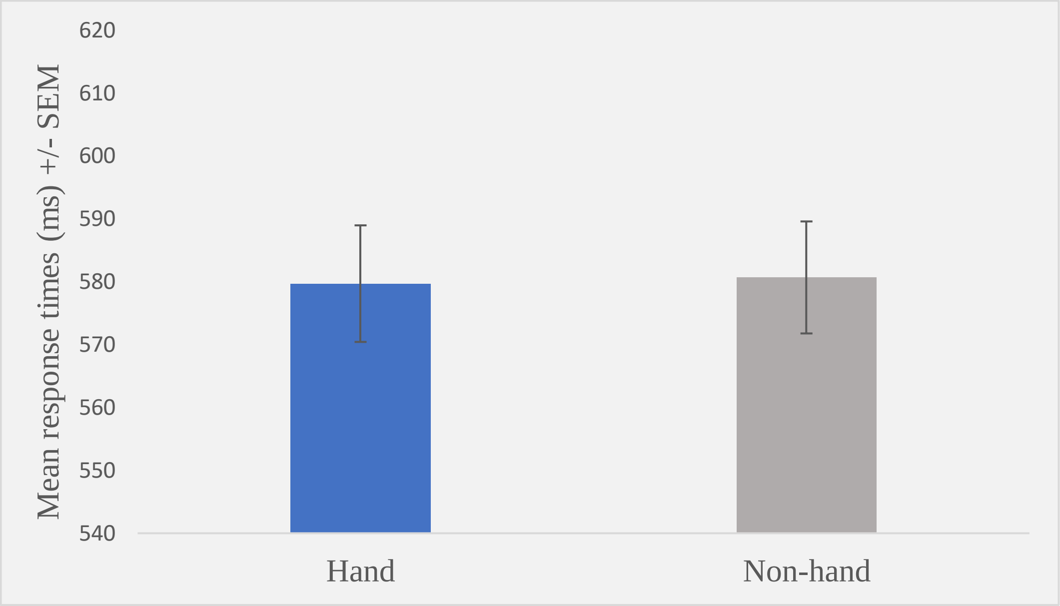


Figure 5.10. Mean RTs while hand- and non-hand related words were processed. Error bars represent the standard error of the mean (SEM).

Additionally, no significant interaction effect was found between AoA and Hand Relatedness (F (1, 39) = 2.06, p = 0.16) or between AoA and Frequency (F (1, 39) = 1.3, p = 0.27). However, a significant interaction effect was found between Frequency and Hand Relatedness (F (1, 39) = 5.3, p = 0.02, η^2 = 0.1). As highlighted in Figure 5.11, the effect for Hand Relatedness only applied to low frequency conditions. Here, hand-related words that were low in frequency (585 ms) elicited quicker hand RTs than non-hand related low frequency words (591 ms). There was no significant interaction effect between AoA, Hand Relatedness, and Frequency (F (1, 39) = 3.1, p = 0.09).

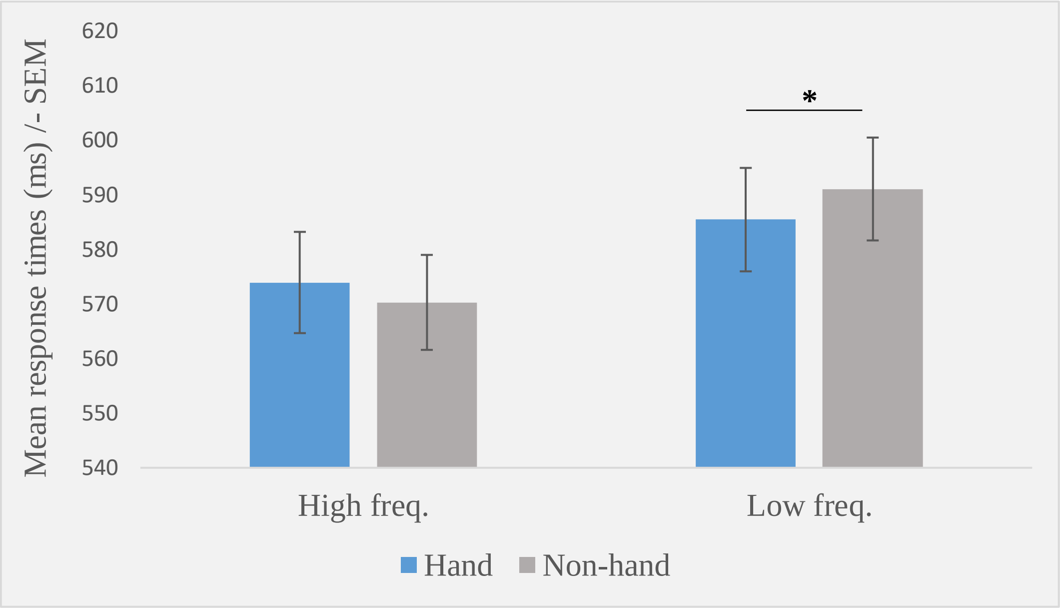


Figure 5.11. Interaction effects between Frequency and Hand Relatedness. Error bars represent the standard error of the mean (SEM). *denotes that p = < 0.05.

Though there was no significant interaction effect between AoA and Hand Relatedness, given that we split the file by AoA in the younger group experiment, we decided to do the same here. This analysis allowed us to examine the effect of Hand Relatedness in relation to early learned stimuli, and separately, in relation to late learned stimuli. Here, it was found that early learned hand-related words did not elicit significantly quicker hand RTs than early learned non-hand related words – though there was a descriptive difference between the two (567.1 ms vs. 571. 4 ms, respectively). Additionally, late learned hand-related words did not elicit significantly slower hand RTs than late learned non-hand related words (592.2 ms vs. 589.9 ms, respectively – see Figure 5.12).

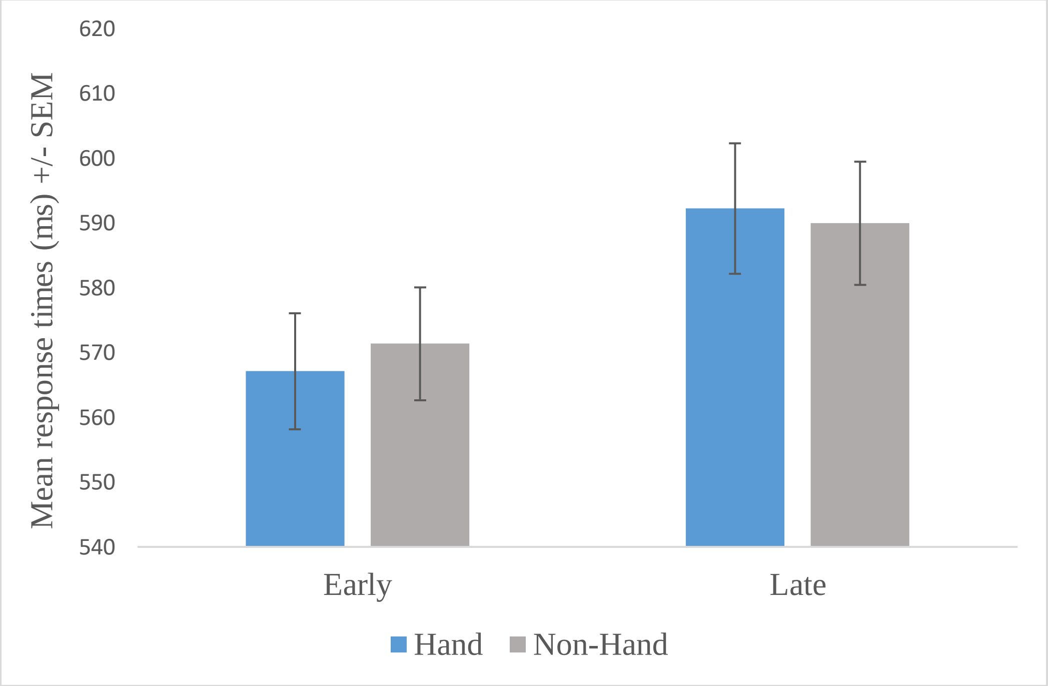


Figure 5.12. No significant interaction effect between AoA and Hand Relatedness. Error bars represent the standard error of the mean (SEM).

5.3 Discussion

The current experiments tested the effect of *age of acquisition* (AoA) on the embodiment of language. Explicitly, they tested whether or not the expected effect of hand-relatedness (i.e., a difference in RTs to hand-related vs. non-hand related stimuli) remained when AoA was included as a factor. First, using a lexical decision task (LDT) and younger participants, we tested the effect of AoA on motor-related language while controlling for word frequency. Here, many effects of note were found. For instance, overall, the analysis showed that high-frequency words elicited significantly quicker hand RTs than low-frequency words. A significant interaction effect was also found between Frequency and AoA. Specifically, we found that hand RTs to high-frequency words acquired early in life (i.e., up to 7 years old) were significantly quicker than to low-frequency words learned during the same early period. A similar trend of quicker hand RTs to high-frequency words was observed ($p = 0.059$) while late acquired words (i.e., learned after 7 years old) were processed. Taken together, these results mirror previous findings which have shown that high-frequency words elicit quicker responses in experimental tasks than low-frequency words (e.g., Arnon & Snider, 2010; Brysbaert, 2018; Ellis, 2002). Moreover, our finding adds to the large body of literature which highlights the importance of controlling for word frequency in psycholinguistic experiments.

Further, with our younger sample, we found a significant main effect of AoA on hand RTs. Overall, early acquired words elicited significantly quicker hand RTs than late acquired words. However, a significant interaction between AoA and Hand Relatedness was also found, and this finding is of particular interest. Here, we found a difference in the pattern of interaction between Hand Relatedness and early AoA and Hand Relatedness and late AoA. For early acquired words, hand-related stimuli elicited quicker hand RTs than non-hand related stimuli, and a split-file analysis confirmed this effect to be significant. However, the opposite pattern was found for late acquired words, as hand-related words learned after approximately 7 years old elicited slower hand RTs than non-hand related words learned during the same period, which a split-file analysis also confirmed to be significant. Given that hand RTs were our measure of embodiment, this difference in the effect of Hand Relatedness within early acquired and late acquired categories suggests that in a younger sample, the degree to which language was embodied was related to when the language was acquired, or AoA.

Potentially, this finding is a challenge for language embodiment theories, as it questions the conclusions derived from the many experiments which have found that similar hand-related words (i.e., verbs, nouns, adjectives) modified hand-motor activity during language processing tasks (see Buccino et al., 2005; Marino et al., 2011, 2014; Gough et al., 2013, respectively). Generally, researchers have concluded that these effects resulted, because processing language is an embodied process that is based upon experiences of the content to which the language refers (Buccino et al., 2005; Gough et al., 2013). However, the current finding suggests that language embodiment may be more applicable to *early* physical experience and thus early learned words, and the hand-related effects that typify many language embodiment experiments could actually reflect the influence of AoA. At a minimum, this suggests that embodiment researchers should consider controlling for AoA, so as to eliminate its potential as a confounding variable. However, as discussed in Chapter 4, AoA is generally not being considered by researchers, so it is not quite clear whether or not the majority of embodiment effects would still stand if AoA was considered – hence the challenge for embodiment theories.

Our finding with younger participants, which suggests that early learned words are quite closely related to motor experience, is perhaps not too surprising. For example, it has long been proposed that early learning is quite interactive, and children often learn during their early years through physical experience (Piaget, 1952; Wellsby & Pexman, 2014; Cartmill et al., 2014). It is quite conceivable that these principles would also apply to language learning, and that early learned words referring to hand actions and manipulable objects (e.g., *bring*, *coat*) would be learned through hand-motor experience of the words` referents. Early learned, non-hand related words (e.g., *cry, zoo*) could also be learned through physical experience, but this experience may not involve hand-motor activity or would involve hand-motor activity to a much lesser degree. It is plausible that these differences would result in a significant difference in hand RTs when early learned, hand-related and early learned, non-hand related words were processed – particularly with such a young sample (*M* = 22.3) – as their physical interactions with early words` referents would not have been all that long ago.

Initially, our finding that late learned, hand-related words had no motor advantage over late learned, non-hand related words seems a little surprising. However, this finding could simply reflect differences in language acquisition between early childhood and subsequent years. As highlighted, early language learning is often acquired through direct perceptual means, in that, in this period, one tends to learn words through sensory experience of the words` referents (i.e., vision, touch, smell etc.) (Borghi et al., 2019; Hernandez, 2013). Contrastingly, late language learning is often facilitated via linguistic means, in that, language learned in this period is often acquired through relations with other language and not through direct perceptual experience (Borghi et al., 2019). It is possible that these differences in acquisition could result in differences in neural representation, which in turn would result in late learned, hand-related words having no motor advantage in an LDT.

That late learned, hand-related words elicited significantly slower motor activity in our younger sample than late learned, non-hand related words could have been due to the relationship between the sample in the experiment and some of the stimuli employed. For example, some of the words used in the late learned, non-hand related category referred to practices and terminology that our younger sample (primarily of university students) would be regularly exposed to (e.g., *assess, phrase, flaw*) – potentially facilitating quick recognition of such words. In addition, some of the late learned, hand-related words referred to actions and objects that the sample may have not been exposed to (e.g., *bind, pendant, chisel*), and these differences could have influenced slower hand responses while this category of words was processed. One of the limitations of our design was that we did not test participants` experiences of the actions and objects that the stimuli described. Perhaps future studies could assess samples post-experiment to gauge their knowledge and experience of the actions and objects that presented stimuli described – as per previous studies (e.g., Yee et al., 2013).

Our second LDT tested the same stimuli within the same design but used a non-university sample of older adults (i.e., aged 50-65 years old). However, the questions surrounding theories of language embodiment were further compounded by the findings from this experiment. For example, as before, we found significant main effects for AoA and for Frequency – in the same direction as the earlier experiment – early learned words and high frequency words elicited quicker hand RTs overall. Additionally, as with the younger participants, we found no significant main effect for Hand Relatedness. However, in contrast to the LDT with younger participants, we found no significant interaction effect between AoA and Hand Relatedness (though the interaction pattern was the same). Essentially, with the older participants, early learned hand-related stimuli offered no advantage over early learned non-hand related stimuli, and late learned hand-related stimuli were not disadvantageous in comparison to late learned non-hand related stimuli. The only other effect of note in the older adult experiment was a significant interaction effect between Frequency and Hand Relatedness. Here, the analysis showed that hand-related stimuli were only advantageous over non-hand related stimuli during low frequency conditions. Thus, overall, the older adult LDT only found support for the embodiment of language in relation to low frequency word conditions. This, in addition, to the results from our younger participant experiment leaves many questions for theories of language embodiment – and again, it suggests that AoA is a potential factor that should be considered.

The difference in results from the younger and older adult experiments warrant further examination. For example, as highlighted, the effect of hand-related stimuli on younger participants` RTs depended upon the age at which the language had been learned; early learned language that was hand related elicited significantly quicker RTs than early learned language that was non-hand related. However, this interaction effect was not observed with the older adults, which suggests that RTs to early learned hand-related language may have been slower overall with this group, whereas the general effect for AoA remained. Perhaps these findings are due to the older sample being slightly less physically active than the younger group, which would plausibly inhibit their motor responses. Moreover, for the older adults, more time has passed between their motor learning of the early words` referents, which could have resulted in a reduced advantage for early hand-related stimuli.

Additionally – with the older sample – late learned hand-related language did not elicit slower RTs relative to late learned non-hand related language. Potentially, this result could have been influenced by older adults` experience, too. Explicitly, as posited, the younger sample could have had minimal or even no experience of the corresponding practices and objects described by presented words such as *bind, pendant,* and *chisel* – facilitating slower RTs during the late learned hand-related condition. In contrast, the older adult sample could have more direct experience with the referents – facilitating quicker RTs during trials containing late hand-related stimuli (relative to the younger group). It is also possible that the older adult group, having been mostly recruited outside of MU, were not as regularly exposed to words such as *assess, phrase, and flaw,* which could have potentially resulted in slower recognition of such words and thus slower RTs. Regardless, the differences between samples highlights the tentative nature of Hand Relatedness when AoA is controlled and the stronger overall influence of AoA across the lifespan. Moreover, differences imply that Hand Relatedness could be associated with and influenced by age. Perhaps there are other factors that influenced RTs, too – such as word imageability – which we did not control for, and that these factors are also related to the participant's age, their level of experience, and AoA. Further research on the analysis of all potential influencing factors is needed to disentangle these issues.

Taken together, on the one hand, our findings contrast with Reifegerste et al.`s (2021) who found that older adults were mostly impaired during the processing of non-hand related stimuli. However, as discussed, results with our older group – in contrast to the younger one – also imply that late learned hand-related language did not appear to elicit slower RTs than late learned language that was non-hand related. This suggests that older adults` processing of late learned non-hand related language may have been slightly inhibited in this condition, which partially supports Reifegerste et al (2021). It must also be noted, though, that Reifegerste et al. (2021) performed a between-groups analysis of younger vs. older participants, whereas we did not; thus, a direct comparison is slightly misleading. Moreover, it is important to stress that mean RTs in our older adult experiment were actually slower overall than with our younger experiment (approximately 70 ms); however, the older adult experiment was also run online, so the environment was not as controlled as with the younger in-person participants. Additionally, the older group LDT processed one block of stimuli (i.e., 180 trials), while the younger group processed the same block twice (i.e., 320 trials). Future work could run the double-block LDT with in-person adults of the same age group and conduct a between-groups analysis with a younger group. A future experiment could also include an intermediate age group (i.e., aged 30-39 years old) and compare effects here with effects from the younger and older groups. Potentially, this could help to establish the stage at which hand-related effects begin to change across the lifespan.

In sum, our younger participant experiment found that the effect for hand-related stimuli was intertwined with *age of acquisition* (AoA). Separately, with older participants, we found that the effect for hand-related stimuli interacted with word frequency, AoA, and participants' age. There are many implications to these findings and many remaining questions for embodiment researchers – including our own group. Future motor-related language experiments should aim to control for AoA so as to eliminate its potential as a confound. In addition, to support embodied accounts, future work will need to show that hand-related word effects can still be observed when AoA is accounted for and that language learned after 7 years old also modifies motor activity. Moreover, to show that embodiment persists across the lifespan, findings would need to extend to samples over the age of 50.

Chapter 6

Language Embodiment and The N400

Abstract

The N400 is a negative going event related potential (ERP) that peaks approximately 400 ms after word presentation (Lau et al., 2008). Typically, N400 amplitude has been associated with stimulus congruency – larger N400s are elicited when stimuli are incongruent with context (Marrero et al., 2017). Using EEG, the current experiment further investigated this phenomenon in relation to motor-related word pairings. Participants (N = 24) were presented with four different prime/target word conditions. In each condition, the prime word bore some relation to the target – either motor (e.g., *pea, pill*), semantic (e.g., *chemist, pill*), unrelated (e.g., *wardrobe, pill*), or pseudo (e.g., *rosw, pill*). Participants were instructed to read onscreen words silently and carefully, and N400 activity was measured during each respective condition. In relation to amplitude and peak latency at electrode Cz, no significant main effect for prime/target condition was found. Additionally, Bonferroni corrected *post hoc* tests found no significant difference between the semantic vs. unrelated condition or the motor vs. unrelated condition. Potential confounds and possible future directions are discussed within.

6.1 Introduction

Typically, theories of *language embodiment* propose that language and action experience are inter-related and that processing language is grounded upon the actions, objects, or events to which the language refers (Barsalou, 1999; Buccino et al., 2018; Gallese, 2008; Gough et al., 2013; Glenberg & Gallese, 2012; Marino et al., 2011; Pulvermüller, 2005; Zarr et al., 2013; Zhang et al., 2016). Embodiment theories have found much support for via neuroimaging, behavioural, and brain stimulation studies which have tested the effect of processing motor-related language on motor activity. For example, neuroimaging studies have shown that processing words (e.g., Hauk et al., 2004) and sentences (e.g., Tettamanti et al., 2005) describing hand actions (e.g., *to wash*) and foot actions (e.g., *to kick*) activates the specific regions of premotor and primary motor cortex that are active during hand actions and foot actions, respectively. These findings and similar ones from hand-related noun studies (see Dreyer et al., 2020) suggest that the representation of the word is directly related to the action/object described – hence the similar neural activations during action/object language processing and action execution (Buccino et al., 2018; Dreyer et al., 2020; Marino et al., 2011).

Findings from behavioural studies of verbs (e.g., Gianelli et al., 2020; Klepp et al., 2017; Sato et al., 2008) and nouns (e.g., Buccino et al., 2018; Glover et al., 2004; Marino et al, 2011,2014) have also shown that processing hand-related stimuli can modify hand motor activity – which further suggests that the word and the action/object described are closely related. For example, Buccino et al. (2005) presented hand-related (e.g., *he wrote the essay*), foot-related (e.g., *he kicked the ball*), and abstract action sentences (e.g., *he enjoyed the sight*) and required participants to perform a hand or foot response when a concrete action was described. The study found that hand-related sentences elicited significantly slower hand RTs when hand responses were performed, whereas foot-related sentences elicited significantly slower RTs during the foot response condition. It has been proposed that these findings result because the hand motor activity elicited by the hand-related sentences impacts the production of the subsequent hand response (Buccino et al., 2005, 2018; Marino et al., 2014) – implying that the representation of the language is closely related to the action described.

In addition, embodied language processing theories are supported by findings which have shown that processing nouns referring to objects upon which the body can act activates and uses cortical motor regions that are activated during object interactions. For instance, Marino et al. (2011) found that processing nouns referring to hand-related objects (e.g., *pencil*) inhibited hand RTs. Contrastingly, a behavioural experiment by Zhang et al. (2016) showed that processing pictures and words referring to hand-related objects (e.g., *pen*) facilitated quicker hand RTs which were performed from 600 ms after word presentation. These findings and others (see Marino et al., 2014; Buccino et al., 2018) are thought to be due to the objects` features described by the noun providing the motor system with the potential to act upon the objects. Resultingly, during language processing, motor activations can either inhibit an early motor response or facilitate a later response – all of which support the assertion that language processing is an embodied phenomenon that is closely related to the motor experiences to which the language refers.

Overall, there is much neuroimaging, behavioural, and brain stimulation evidence (see Buccino et al., 2005; Repetto et al., 2013) to show that processing motor-related language uses and/or impacts upon motor activity; thus, embodied language theories are quite well supported – though this is still disputed by some (e.g., de Zubicaray et al., 2013, 2021; Papeo et al., 2009). However, there are further potential ways to test the interaction between language processing and motor activity, which would allow for a closer examination of the topics. For instance, one potential way would be to measure the effect of motor-related language on a cluster of brain activity known as the N400. Specifically, the N400 is a negative going electrical potential that peaks approximately 400 ms after word presentation and is associated with a centroparietal scalp distribution (Lau et al., 2008). Typically, N400 amplitude has been associated with stimulus congruency, with a larger N400 elicited when stimuli are incongruent with context (Marrero et al., 2017). The N400 was first discovered in an experiment by Kutas and Hillyard (1980). These researchers reported a negative going brain wave, recorded from Fz, Cz, and Pz electrodes (i.e., frontal, central, and parietal sites, respectively), that occurred between approximately 250-600 ms after stimulus presentation. Specifically, Kutas and Hillyard (1980) found significantly greater N400 amplitude as participants processed a strongly incongruent (e.g., *he took a sip from the transmitter*) vs. a moderately incongruent condition e.g., *he took a sip from the waterfall*). Thereafter, the authors postulated that increased N400 activity could be related to a disruption to expectations or semantic incongruency.

Since then, the effect of congruency/incongruency on the N400 event related potential (ERP) component activity has been examined many times in language processing studies. For instance, Tromp et al. (2018) conducted a novel study which combined EEG with virtual reality (VR). In their study, participants were submerged in a virtual restaurant where they viewed an object on a plate (e.g., a piece of salmon). A sentence was then spoken by a guest in the VR world, which was either compatible (e.g., *I just ordered this salmon*) or incompatible with the presented object (e.g., *I just ordered this pasta*). An analysis of the N400 ERP component showed significantly greater negative amplitude when incompatible sentences were processed (Tromp et al., 2018) – highlighting the influence of incongruent language on the brain`s electrical activity.

A more recent study by Cervetto et al. (2021) used EEG alongside a lexical decision task (LDT) to show that N400 amplitude can be reduced when stimuli are congruent with a corresponding action. Here, participants were presented with manual action verbs (e.g., *cut*), non-manual action verbs (e.g., *walk*), abstract verbs (e.g., *improve*), and pseudo verbs (e.g., *coltar*) and were required to decide, via button press, whether or not the stimulus was a real word or non-word. Cervetto et al. (2021) measured N400 activity from three six-electrode scalp regions of interest (ROI) – a central-posterior ROI, a left posterior ROI, and a right posterior ROI; these scalp regions had been reliably used in previous language-related EEG work (see Manfredi et al., 2017). An analysis of these regions showed that manual verbs elicited reduced N400 amplitude relative to processing non-manual action verbs and abstract verbs. The researchers suggested that this modulation occurred, as the manual verbs described actions congruent with the subsequent bodily response (i.e., the hand response) – thus reducing N400 amplitude.

A slightly later study by Al-Azary et al. (2022) also showed how congruency between presented stimuli and task requirements can impact upon N400 activity. In the experiment, words referring to objects that were highly easy to interact with (e.g., *wallet, napkin*), words that were less easy to interact with (e.g., *robot, rocket*), and abstract words (e.g., *guilt, risk*) were presented – participants had to decide (via hand response) whether stimuli described touchable or untouchable entities. N400 ERPs were examined around a cluster of frontal central, and parietal sites (e.g., F8, Cz, Pz), and the experiment found differential activations at most of these sites. For example, at electrode Cz, low body interaction words elicited greater N400 amplitude than high body interaction words (Al-Azary et al., 2022). As with the Cervetto et al. (2021) study, this finding suggests that greater congruency between hand-related stimuli and a corresponding task can attenuate N400 amplitude. Interestingly, Al-Azary et al. (2022) performed a second experiment, but this time, participants had to decide whether the same stimuli were concrete or abstract. This analysis found no differences in N400 amplitude between low body and high body word categories – suggesting that having to make a concrete/abstract distinction, which arguably makes features of motor stimuli less salient, impacts upon N400 activity.

Taken together, findings from the above studies and many others (see Cocquyt et al., 2022; Marrero et al., 2017; Wang et al., 2019) have shown that the N400 is a reliable measure of the brain's response to congruent/incongruent language. Additionally, the Cervetto et al. (2021) and Al-Azary et al. (2022) studies suggest that motor-related stimuli can attenuate N400 amplitude during certain conditions. The current experiment further investigated this phenomenon in relation to motor-related word pairings, which, to the best of the current author`s knowledge has yet to be explored. For example, processing language that is semantically related in a classical sense (e.g., *bread, butter*) typically elicits reduced N400 activity, whereas unrelated language (e.g., *bread, soap*) tends to produce greater N400 amplitude (Kappenman et al., 2021). The current experiment used EEG to test the degree to which hand-related word pairings (e.g., *nest, bowl*) elicited a reduced N400 – relative to the processing of unrelated pairings. Specifically, hand-related pairings eliciting a reduced N400 would imply that the brain groups motor-related stimuli (i.e., that which is graspable) in a similar manner to stimuli related in a classical semantic sense. This would further suggest that processing words describing different types of objects is related to the objects` graspable features – a proposition that is at the heart of many embodied language theories (Buccino et al., 2005, 2018; Gough et al., 2012; Marino et al., 2011;2014). To test this, trials containing a prime and target word that were motorically related (e.g., *pill, pea*), semantically related (e.g., *pill, chemist*), unrelated (e.g., *pill, pea*), or a pseudo prime and target condition prime (e.g., *euog, pea)* were presented – participants were instructed to read onscreen words silently and carefully, and N400 amplitude and peak latency were measured during each respective condition (i.e., motor vs. semantic vs. unrelated vs. pseudo). Before the EEG experiment, to test our stimuli and task, a pilot behavioural experiment was conducted.

6.2 Method

6.2.1 Pre-registration

The EEG experiment and pilot behavioural task were pre-registered on *AsPredicted.com* on 11/10/2022. https://aspredicted.org/see_one.php

6.2.2 Participants

6.2.2.1 Behavioural participants

As the purpose of the behavioural experiment was simply to trial the EEG stimuli and task, a small sample was recruited (*N* = 12). No participant from the behavioural experiment partook in the EEG work. Due to an error, data from five participants were overwritten; thus, data from 7 participants were left for analysis. These participants were all aged between 18-30 years old (*M* = 23.5, *SD* =8.1). Primarily, these participants were sourced from a research participation pool in Maynooth University`s (MU) Department of Psychology; some were also recruited from the primary researcher`s contacts. Those from the research pool received credit for their participation. According to self-reports, five participants were female while two reported to be male; no participant reported to be any other gender. This group were also right-handed (*M* = 23.5, *SD* =8.1) as per the Edinburgh Handedness Inventory (1971) and all spoke English as a first language. The pilot behavioural experiment was reviewed and passed by MU University`s Biomedical & Life Science Sub-Committee (BSRESC-2022-2468239).

6.2.2.2 EEG participants

To determine sample size for the EEG experiment, a G*Power analysis was conducted. Based upon this analysis, to examine repeated factors across four levels – using an alpha of 0.05 with 80% power for a medium partial eta effect (i.e., eta of 0.06 = equivalent to Cohen`s f of

0.2526456), G*Power suggested a sample of 24 participants. However, we received ethical approval to test between 30-50 participants – as in some cases data would need to be excluded and given that the N400 had not yet been examined in relation to motor-related pairings. Overall, we recruited 28 participants. One participant disclosed that they had attention deficit hyperactivity disorder (ADHD) – which is associated with EEG noise (Pertermann et al., 2019) – so their data were not analysed. For reasons unknown, experimental triggers were not sent for another participant, while two more participants did not answer a sufficient number of repeat word questions (see Statistical analyses section). All in all, data from 24 participants were used; all were aged between 18-40 years old (*M* = 22.3, *SD* = 5.8). As with the behavioural experiment, the EEG participants were either sourced from the MU University`s Department of Psychology research participation pool, for which they received course credit or from the primary researcher`s contacts. According to self-reports, 16 of these participants were female while 8 reported to be male – as before, no other gender was reported. This group were also right-handed (*M* = 86.9, *SD* = 13.9) as per the Edinburgh Handedness Inventory (1971). The EEG experiment was also reviewed and passed by MU University`s Biomedical & Life Science Sub-Committee (BSRESC-2022-2468239).

6.2.3 Stimuli

6.2.3.1 Behavioural stimuli

The behavioural stimuli consisted of 30 target words (e.g., *broom*), 30 motor primes (e.g., *spade*), 30 semantic primes (e.g., *witch*), and 30 unrelated primes (e.g., *truck*) (see Appendix E). Word categories were agreed upon by all three researchers involved in the thesis. Additionally, 30 pseudo words were used as targets, while a different set of 60 pseudo words were used as primes. The pseudo words were created in Microsoft Excel, version 16.0, by randomly ordering the letters that comprised the real English words in the experiment and constructing new pseudo words. The pseudo words and real words were also matched for number of letters. Prime stimuli categories (i.e., motor vs. semantic vs. unrelated) were balanced for various psycholinguistic variables using the MRC Psycholinguistic Database (Coltheart, 1981). Firstly, written frequency was assessed on the Kucera-Francis (1967) written frequency scale. Here, there was no significant main effect for prime condition (F (2, 77) = 2.3, p = 0.11). Secondly, written frequency was assessed via the Thorndike-Lorge written frequency scale. Here, there was also no significant main effect for prime condition (F (2, 80) = 1.37, p = 0.3). Additionally, prime stimuli were balanced for number of syllables, with no significant main effect for prime condition (F (2, 86) = 2.46, p = 0.09).

6.2.3.2 EEG stimuli

The EEG stimuli consisted of the same 30 target words, 30 motor primes, 30 semantic primes, and 30 unrelated primes that were used in the behavioural experiment. Additionally, 30 of the pseudo words that were used as primes in the behavioural experiment were employed. Stimuli were balanced as per the behavioural experiment.

6.2.4 Procedure

6.2.4.1 Behavioural procedure

All testing took place at the MU University Department of Psychology`s testing cubicles. For the behavioural experiment, the participant sat on a chair in a dimly lit cubicle approximately 55 cm from a 15-inch standard 4:3 ratio computer screen. The computer screen and keyboard were placed on a small table, just in front of the participant`s chair, and the keyboard was placed on the ground near the participant`s feet. The participant was first provided with an information sheet outlining the basic nature of the research; a consent form was also attached to this sheet, which the participant completed, manually. The participant was informed that the experiment would consist of a number of onscreen trials, and that each trial would present two string of letters, one at a time, in the centre of the screen. They were instructed to read the letter strings carefully and to respond – by quickly pressing the spacebar on the keyboard with the right foot only – whenever the second letter string (in green font) was a real word. The foot press was used to try to remove the advantage of using the hand to respond to hand-related stimuli. Participants were also instructed to refrain from responding when the letter string was not a real word. The instructions for the experiment were then presented onscreen, and the experimenter ascertained if each participant understood the task. Additionally, before the behavioural experiment began, the participant took part in a brief practice session (i.e., 5 trials), the purpose of which was to familiarise the participant with the task. The experiment commenced when the participant pressed the spacebar on the computer keyboard.

The behavioural experiment was presented via *EPrime* Psychology Software Tools, version 3.0 (2022). A single behavioural trial took a maximum of 4100 ms to complete, and there were 360 trials in total (i.e., two blocks of 180 trials). Each trial began with a fixation cross that was presented for 1000 ms. A prime word was then presented for 200 ms (e.g., *pear*). After a randomised interval of between 900-1100 ms, the target word appeared for 200 ms (e.g., *bulb*). Here, the participant was required to respond, with their right foot only, whenever the target was a real word. A blank screen then appeared for a random time of between 1400-1600 ms, before the experiment moved to the next trial (see Figure 6.1). All stimulus presentation times were adapted from Kappenman et al. (2021). The experiment took approx. 24 minutes to complete, and there was an option for a break after 180 trials. Trials were presented in a random order.

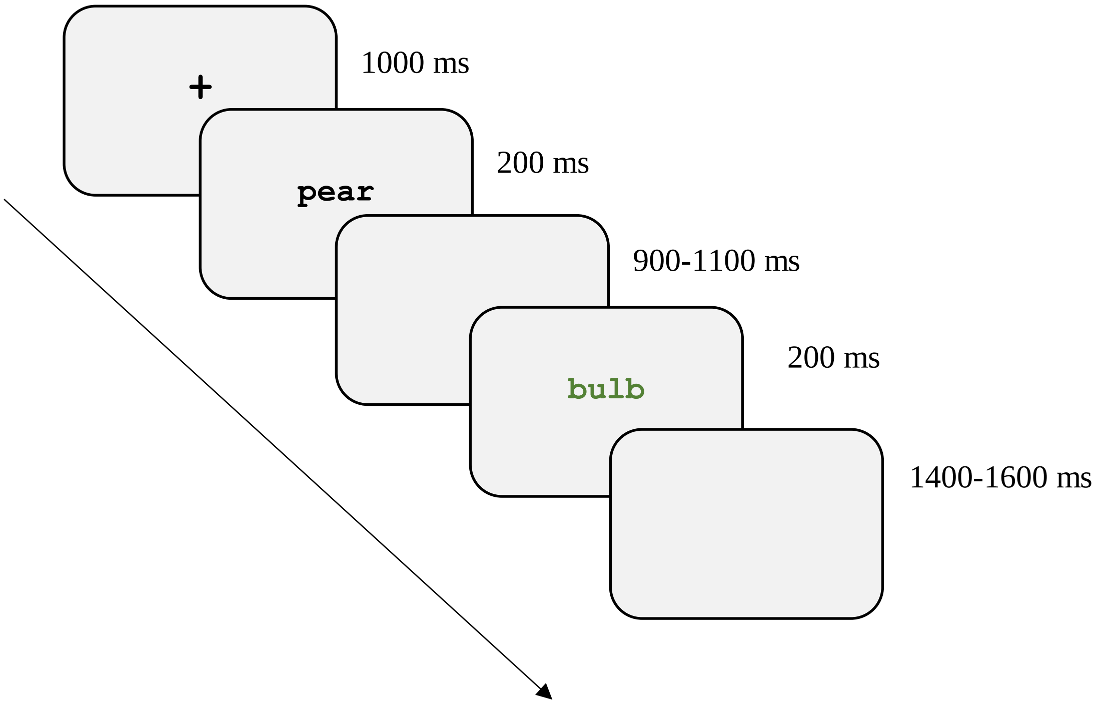


Figure 6.1. Example of a motor prime/target behavioural trial. Fixation cross appeared for 1000 ms before a prime (e.g., *pear*) appeared for 200 ms. A blank screen was then presented for a random time of between 900-1100 ms, before a target word (e.g., *bulb*) was presented for 200 ms. Another blank screen appeared for between 1400-1600 ms – the experiment then moved to a new trial.

6.2.4.2 EEG procedure

Each participant who underwent EEG was also first provided with a consent form and an information sheet that outlined the general nature of the experiment. After providing consent and completing the Handedness Inventory Form (Oldfield, 1971), the participant was verbally informed that the experiment consisted of a number of trials, and that each trial would present two letter strings in the centre of the screen, one at a time. They were further instructed that they would have to read the words carefully and silently and to focus on stimuli at all times. Participants were also informed that some trials would contain repeated word questions, and here, they would be presented with a word and required to decide (via pressing Y for yes, N for no) whether or not the word had just appeared in the trial. Thereafter, the participant was fitted with the EEG cap and 32 electrodes (see General methods – Chapter 2).

When seated in the Faraday cage, the instructions for the EEG experiment were presented on the onscreen monitor, and the experimenter ascertained if each participant understood the task. The experiment began when the participant pressed the spacebar on the computer keyboard. Overall, the EEG experiment consisted of two blocks of 120 trials (i.e., 240 trials in total). The block was repeated to try to improve signal to noise ratio – as per previous studies (e.g., van Dam et al., 2012). All items were presented in the centre of the screen, and all stimuli were displayed in black Courier New size 32 font on a silver background. The EEG experiment was also presented via *EPrime* Psychology Software Tools, version 3.0. (2022) on a 15-inch standard 4:3 ratio computer screen. Each trial began with a fixation cross that was presented for 1000 ms. A prime word was then presented for 200 ms (e.g., *pill*). After a randomised interval of between 900-1100 ms, the target word appeared for 200 ms (e.g., *pea*). A blank screen then appeared for a random time of between 1400-1600 ms before the experiment moved to a new trial. As with the behavioural experiment, all stimulus presentation times were adapted from Kappenman et al. (2021). On 20/240 trials, to assess whether or not participants were focussed, a repeated word question was presented. Here, participants had to decide whether a presented word had just appeared in the trial. They responded by pressing Y for Yes or N for No on the computer keyboard (see Figure 6.2). The experiment then moved on to the next trial. The experiment took approx. 25 minutes to complete, and there was an option for a break after 120 trials. Trials were presented in a randomised order.

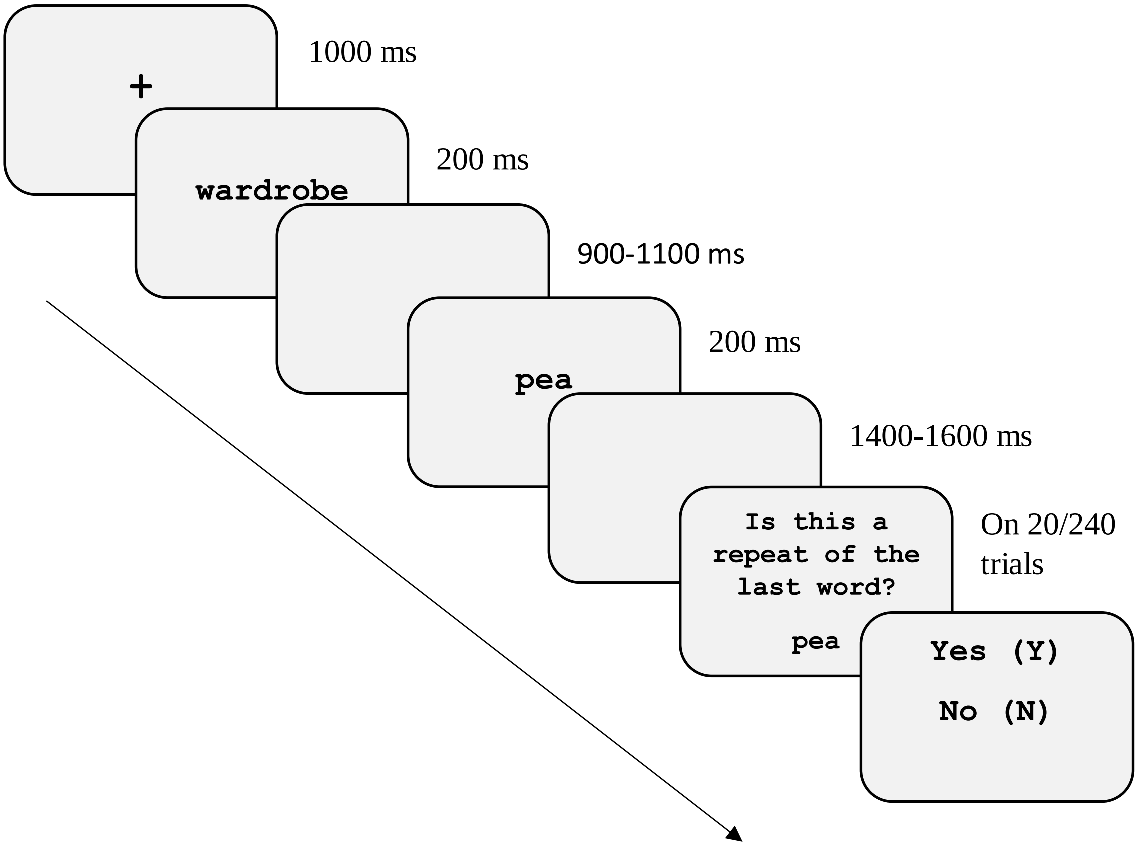


Figure 6.2. Example of an unrelated prime/target EEG trial. Fixation cross appeared for 1000 ms before a prime (e.g., *wardrobe*) appeared for 200 ms. A blank screen was then presented for a random time of between 900-1100 ms before a target word (e.g., *pill*) was presented for 200 ms. Another blank screen appeared for between 1400-1600 ms – the experiment then moved to a new trial. Repeated word questions (requiring a Y/N response) were pseudo-randomly presented at the end of 10% of trials.

6.2.5 Statistical analyses

6.2.5.1 Behavioural data

Behavioural data were cleaned for missed responses and false positives; here, a threshold of 85% was set – as per our previous experiments. Participants had an average response accuracy of 94%, and no participant`s accuracy was less than 85%. Microsoft Excel, version 16.0, was used to compute mean RTs and standard deviations (SDs) for each participant across trials. For each participant, all individual RTs that were 2 SDs quicker/slower than their individual mean were considered as errors and removed from the analysis. Overall, 98% of participants` responses were within 2 SDs of their mean RT. From the remaining data, a mean RT was computed for the four experimental conditions (i.e., semantic prime; motor prime; unrelated prime; pseudo prime). A repeated-measures ANOVA was conducted to test for a main effect of prime condition; Bonferroni corrected *post hoc* t-tests were used to test for differences between specific prime conditions (i.e., motor vs. unrelated primes; semantic vs. unrelated primes). $P < 0.05$ was taken as significance – where appropriate, a star-based system displaying significance was used on the figures (* $p < 0.05$, ****** $p < 0.01$, and ******* $p < 0.001$).

6.2.5.2 EEG data

For the EEG experiment, accuracy for to the 20 repeated word questions was calculated – via the 85% threshold. As stated, two participants` accuracy was below the 85% threshold, so their data were removed – another participant disclosed that they had ADHD, and triggers did not send for one participant. The remaining 24 participants had a mean accuracy of 99% (*SD* = 3.1) for the repeated word questions. Raw EEG data were examined using Brainstorm, version 3.210 (Tadel et al., 2019). Data were sampled at 2048 Hz but were down sampled offline to 512 Hz. To remove bad segments and faulty channels, data were first analysed visually. A high-pass filter of 1 Hz and a low-pass filter of 40 Hz was then used; raw data were once again inspected after the filter was applied. An independent component analysis (ICA) was then performed, with thirty-one components on the raw data. Here, potential blinks, muscle movements, facial movements, and saccades were removed. EEG data were then re-referenced to the average of the 32 electrodes.

Brainstorm was then used to import and average stimulus-locked ERPs. Each event was coded to begin 200 ms pre-stimulus presentation and to end 800 ms post-stimulus onset. Block two triggers were combined with block one triggers to establish an ERP for each condition for each participant (motor prime/semantic prime/unrelated prime/pseudo prime). The ERP extracted from central scalp electrode Cz was chosen for comparative analysis; this location was one of the ones used by Kappenman et al. (2021) upon which the current experiment was based. The outcome variables were mean amplitude and peak latency at electrode Cz relative to the four target conditions. Amplitude was calculated by averaging neural activity at Cz between 300-500 ms post stimulus presentation – relative to each of the four target types. Peak latency was measured by comparing the lowest negative time point for each participant at Cz across each of the four targets between 300-500 ms. Data were then inputted to SPSS. For mean amplitude, a repeated-measures ANOVA was conducted to test for a main effect of prime condition; Bonferroni corrected *post hoc* t-tests were conducted to test for differences between specific prime conditions (i.e., motor vs. unrelated primes; semantic vs. unrelated primes). For peak latency, a separate repeated-measures ANOVA was conducted, which also tested for a main effect of prime condition. As before, Bonferroni corrected *post hoc* t-tests were used to test for differences between the same specific prime conditions. $P < 0.05$ was taken as significance, and where appropriate, a star-based system displaying significant differences was used on the figures (* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$).

6.3 Results

6.3.1 Behavioural results

Mean RTs and SDs for each participant in the behavioural experiment are displayed in Table 6.1. Data were analysed in a repeated-measures ANOVA, which tested for a main effect of prime condition (i.e., motor vs. semantic vs. unrelated vs. pseudo). Here, a significant main effect for prime condition was found (F (3, 18) = 5.97, p = 0.005, η^2 = 0.5). Bonferroni corrected t-tests showed that there was no significant difference between semantic vs. unrelated prime conditions (426.2 ms vs. 433.0 ms, respectively) or between motor vs. unrelated prime conditions (428.2 ms vs. 433.0 ms, respectively).

Table 6.1

Mean RTs and SDs (ms) for each behavioural condition

Condition	**N**	**Mean**	**SD**	**Min**	**Max**
MotorPrime	7	428.2	40.2	393.1	504.4
Semanticprime	7	426.2	29.8	392.8	510.0
UnrelatedPrime	7	433.0	38.2	407.5	492.4
PseudoPrime	7	449.9	41.7	413.9	513.7

6.3.2 EEG results

Table 6.2 and Figure 6.3 show the average N400 amplitude for all participants across each of the four prime conditions at electrode Cz. Figure 6.4 (a-d) highlights the mean amplitude topography relative to each prime condition. ERP data were analysed in a repeated-measures ANOVA, which tested for a main effect of prime condition (i.e., motor vs. semantic vs. unrelated vs. pseudo). Here, no significant main effect for prime condition was found (F (3, 69) = 0.57, p = 0.65) (see Figure 6.3). Bonferroni corrected t-tests showed that there was no significant difference between semantic vs. unrelated prime conditions (-.66 millivolts (mv) vs. -.58 mv, respectively) or between motor vs. unrelated prime conditions (-.75 mv vs. -.58 mv, respectively).

Table 6.2

Mean N400 amplitude (µV) for each prime condition

Condition	**N**	**Mean**	**SD**	**Min**	**Max**
MotorPrime	24	-.75	1.93	-3.95	4.21
SemanticPrime	24	-.66	1.92	-4.30	2.40
UnrelatedPrime	24	-.58	2.3	-4.40	2.47
PseudoPrime	24	-.07	2.1	-2.98	5.45

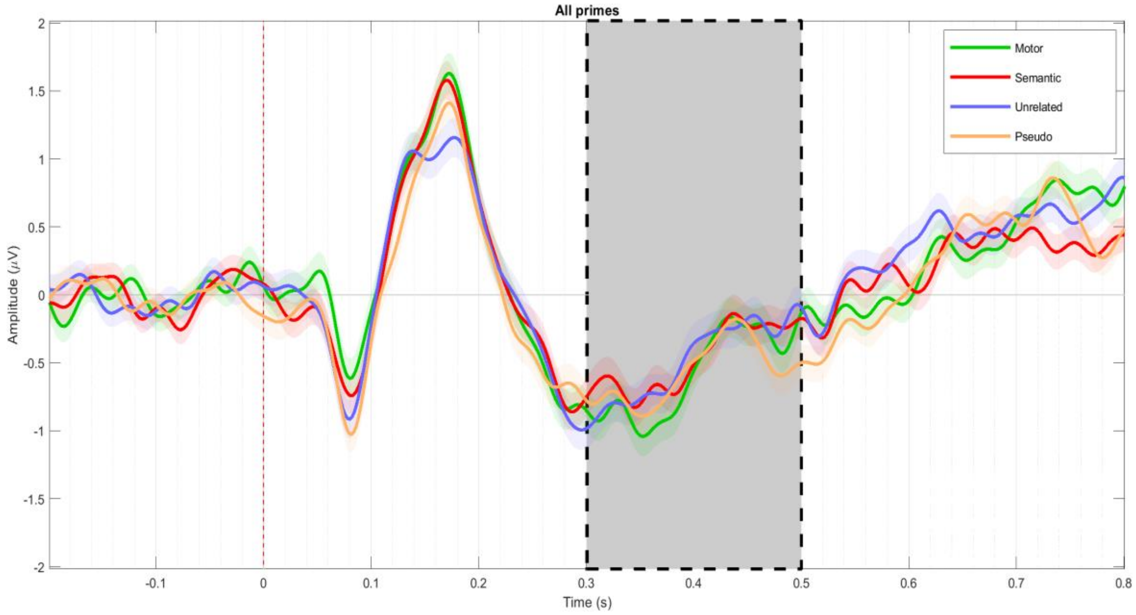


Figure 6.3. N400 amplitude at electrode Cz for each experimental trigger – motor vs. semantic vs. unrelated vs. pseudo. Shaded area represents the 300-500 ms epoch.

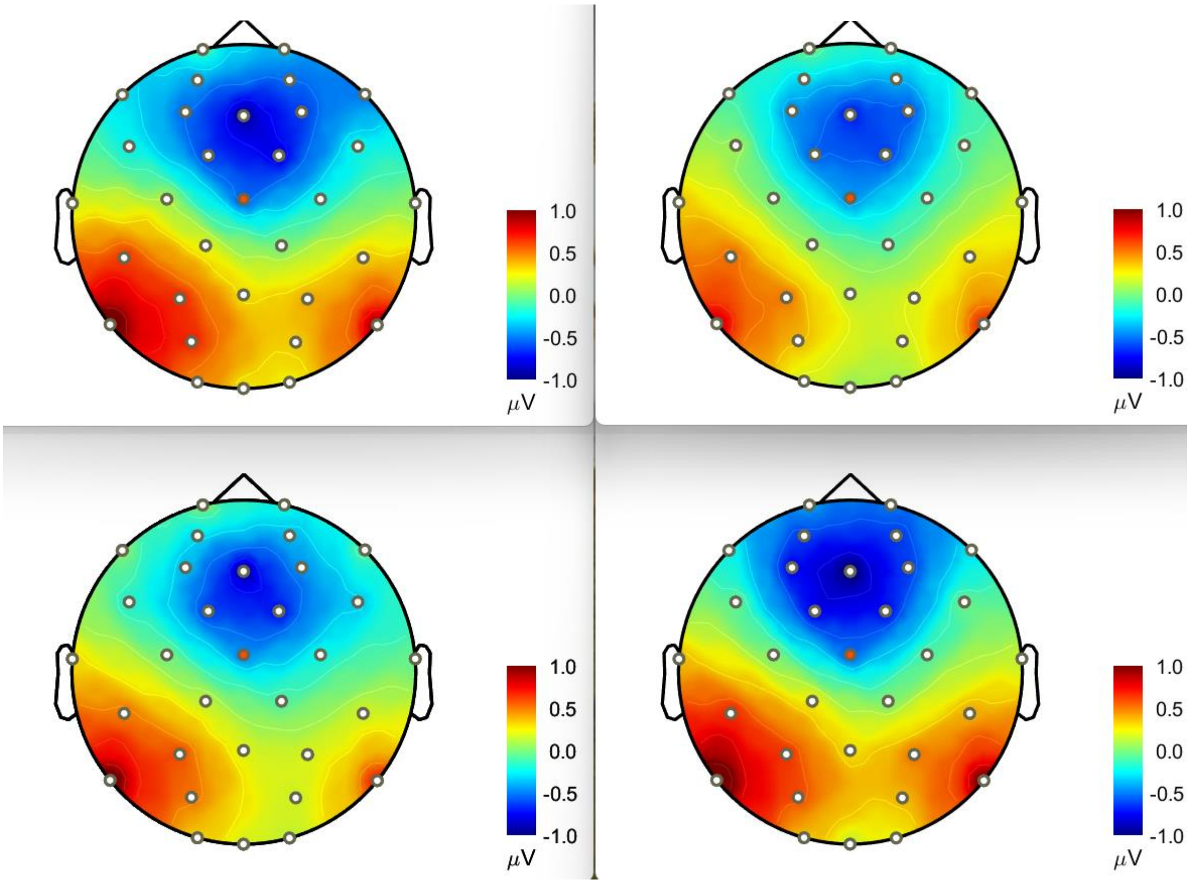


Figure 6.4a. Motor topography

Figure 6.4b. Semantic topography

Figure 6.4c. Unrelated topography

Figure 6.4d. Pseudo topography

Figure 6.4 *(a-d).* Mean 300-500 ms amplitude topography at Cz (highlighted red dot) during motor (a), semantic (b), unrelated (c) and pseudo conditions (d).

Peak latency scores are highlighted in Table 6.3. Peak data were analysed in a separate repeated-measures ANOVA, which also tested for a main effect of prime condition (i.e., motor vs. semantic vs. unrelated vs. pseudo). Here, no significant main effect for prime condition was found (F (3, 69) = 0.23, p = 0.87). Bonferroni corrected t-tests showed that there was no significant difference between semantic vs. unrelated prime conditions (388.4 ms vs. 388.1 respectively) or between motor vs. unrelated prime conditions (406.5 ms vs. 388.1 ms respectively).

Table 6.3

Peak latency (ms) for each experimental condition

Condition	**N**	**Mean**	**SD**	**Min**	**Max**
MotorPrime	24	406.5	5.6	310	500
Semanticprime	24	388.4	6.7	310	490
UnrelatedPrime	24	388.1	6.7	300	500
PseudoPrime	24	369.2	4.2	310	460

6.4 Discussion

The current experiment tested the effect of motor-related language on the N400 ERP component. Specifically, using EEG, it examined whether or not motor-related word pairings (e.g., *crayon*, *cigarette*) elicited a reduced N400 amplitude and change in latency relative to unrelated word pairings (e.g., *mountain*, *cigarette*). Many previous studies had shown that semantic word pairings (e.g., *sleep, dream*) elicited a reduced N400, and the current experiment explored whether or not a similar reduction applied to motor-related pairings. However, our results did not show a significant difference between motor and unrelated prime conditions – nor was the typical semantic vs unrelated difference observed (i.e., reduced N400 activity during processing semantic prime and target words). There are many potential reasons for these results and many factors that need to be considered for future research.

As discussed, the current experiment was based upon earlier work by Kappenman et al. (2021). Accordingly, there were many similarities between this earlier experiment and the current one (e.g., timing of stimuli), but there were some notable differences, too. For example, the earlier experiment presented related vs. unrelated prime conditions only, so each participant saw the target word twice – in one of two conditions. The current experiment presented target words in four different conditions (x 2 repeated blocks), which meant that each participant saw the target a total of 8 times. Thus, the current context for the target word was much broader than just viewing a target word in a related vs. unrelated condition – as per the Kappenman et al. (2021) study. In addition, Kappenman et al. (2021) tested 39 participants, whereas data from 24 were analysed in the current experiment. These factors could have contributed to the different effects across studies.

However, arguably, a more telling difference was that Kappenman et al. (2021) required participants to decide whether or not target words were related to preceding prime words – therefore requiring stimuli to be processed semantically. Interestingly, many of the studies outlined in the introduction for this chapter utilised semantic tasks, too, while Al-Azary et al. (2022) and Cervetto et al. (2021) also found that greater congruency between hand-related stimuli and a corresponding hand activity attenuated N400 amplitude. In the current experiment, participants simply read words silently and did not make decisions about stimuli nor did they perform a hand response. As discussed in Chapter 3, motor effects in language processing can be influenced by task demands, and it is possible that the different requirements between earlier studies and the current one influenced neural activity. Participants in the current study were presented with questions pertaining to stimuli on approximately 8% of trials, for which a hand response was required, and accuracy here was quite high (i.e., 99%). Thus, it is quite probable that the sample were attending to the task, but potentially – not having to make decisions about stimuli and/or perform a hand response could have influenced findings.

Relatedly, previous experiments which have utilised shallow processing tasks have not always found N400 effects – suggesting that neural activity at this epoch is not always automatic (see Cruse et al., 2014; Erlbeck et al., 2014). For instance, Erlbeck et al. (2014) ran a study which presented auditory tones, related/unrelated word pairs, and congruent/incongruent sentences. In one condition, participants listened to stimuli while watching a silent film and pressed a button each time a scene appeared. Another condition required participants to listen to the same stimuli but to press a keyboard key for related word pairs/congruent sentences and a different key when unrelated pairs/incongruent sentences were presented. An analysis at electrodes Cz, Fz, and Pz showed no N400 effect during the silent film condition, whereas a significant N400 effect was found during the semantic condition (Erlbeck et al., 2014). This finding shows that in some instances, N400 effects are related to task requirements, and future research should consider this point. Relatedly, researchers could run the same experiment, with different groups – one of which undertakes a semantic decision task, and one which undertakes the task employed in the current experiment. A group comparison would shed some light as to whether or not N400 activity is influenced by task demands. Researchers could also utilise a hand-related task to further test whether or not congruency between action words and corresponding actions influences N400 activity.

It is also noteworthy that Cz was the only electrode site examined in the current experiment – as per our pre-registration. However, Kappenman et al. (2021) also analysed the N400 at electrode CPz, which forms part of the 64-channel EEG system. Contrastingly, the MU system is 32-channel EEG and does not contain electrode CPz; thus, electrode Cz was chosen as an alternative analysis point. It is possible that an N400 effect would have been observed at other central or parietal sites – such as Pz, P3, Fz, F3, C4. A future experiment could analyse and average activity at these sites in addition to Cz and CPz, which would possibly allow for a more accurate measure of the N400 during semantic/motor/unrelated word processing. Future work could also run each prime condition in individual blocks (i.e., motor/semantic/unrelated/pseudo primes in separate blocks) as opposed to randomly. Potentially, this would allow for greater prime/target salience in each condition which could have a bearing on N400 effects.

Furthermore, it must be noted that EEG data re-referencing in the current experiment was not exactly the same as with the Kappenman et al. (2021) work. Specifically, Kappenman et al. (2021) re-referenced to the average at electrodes P9 and P10, which form part of the 64-channel EEG system. According to the authors, using P9 and P10 allows for cleaner signal than averaging against the mastoids – though, many previous N400 studies have used the mastoids as reference points (e.g., Al-Azary et al., 2022). However, as stated, the MU lab uses a 32-channel system which do not contain electrodes P9 and P10, so these could not be utilised for the current experiment. It is possible that these differences had an influence on the findings, as did choosing to re-reference to the average of all electrodes as opposed to the mastoids. It must also be noted, however, that re-referencing to the average of all electrodes has been utilised in other N400 language-related work (e.g., Cervetto et al., 2021). A future experiment could easily use the current data but re-reference offline to the mastoids instead, which would help to establish whether or not re-referencing had an impact on current findings.

Of course, it cannot be ruled out that a reduced N400 simply does not apply to motor-related word pairings. However, the lack of a semantic vs. unrelated effect suggests that current findings could have been due to experimental design. Future work could account for potential confounds via the methods outlined above. Employing some form of semantic decision task – requiring decisions about prime/ target relations and possibly a hand response would allow for a further test of the theory that effects are related to/influenced by task demands. As it stands, the current experiment has been unable to find evidence of an N400 effect for motor-related pairings. However, as the work here is the first of its kind, many more findings would be needed to confirm or oppose the proposition that the brain categorises word pairings referring to hand-related objects via the objects` graspable features.

Chapter 7

General Discussion

7.1 Overview of thesis aims and findings

The current thesis had several aims – all of which centred around further testing theories of *language embodiment*. Typically, theories of language embodiment propose that language and action experience are inter-related and that processing language is grounded upon the actions, objects, or events to which the language refers (Barsalou, 1999; Buccino et al., 2018; Gallese, 2008; Gianelli et al., 2020; Glenberg & Gallese, 2012; Gough et al., 2013; Marino et al., 2011; Pulvermüller, 2005; Zarr et al., 2013). However, much prior embodiment research had examined motor activity during verb and noun processing only, so current theories have been built upon a relatively limited set of word categories. Chapter 3 further explored *the embodiment of adjectives* – given that this word category had only been examined a couple of times previously (i.e., by Gough et al., in 2013 and by Garafola et al. in 2021). Moreover, adjective representation was of interest as it allowed us to further test the claim that processing language is grounded upon the actions, objects, or events to which the language refers. For example, as explored in Chapter 3, many adjectives express properties related to grasping/approaching actions (e.g., *soft*) or retracting/avoiding actions (e.g., *sharp*), and embodiment of language theories predict that these differences should elicit differences in motor activity during adjective processing. Further, the earlier Gough et al. (2012) study found that adjectives expressing properties related to retracting actions elicited a reduction in motor activity (i.e., arm motor evoked potentials – MEPs) relative to processing adjectives containing properties related to grasping actions. Our work aimed to build upon these earlier findings by further examining the effect of adjectives on motor activity – albeit in a slightly different way. Additionally, testing the potential embodiment of adjectives also allowed us to examine the impact of different levels of processing on motor responses to language.

To examine the effect of adjectives on motor responses, three separate experiments requiring differing levels of processing were presented to three different groups of participants.

In all three experiments, participants were presented with trials containing an adjective (negative – e.g., *hot*; non-negative e.g., – *soft*; pseudo – e.g., *htrtc*) followed by a noun (hand related – e.g., *iron*; non-hand related – e.g., *sound*). In the GoSignal experiment (Experiment 3.1), the participants simply had to read the onscreen words and respond to a cue (i.e., a green signal) that came onscreen at a random time between 0-200 ms after noun presentation. In essence, this experiment allowed for an analysis of automatic responses to language, as no decisions/categorisation had to be performed in relation to presented stimuli.

The results from the GoSignal experiment showed that hand-related nouns elicited significantly quicker hand RTs overall than non-hand related nouns; this was in line with existing research which had shown that processing hand-related nouns can impact upon subsequent hand motor activity (see General introduction). However, it was also hypothesised that the properties described by the negative adjectives could prepare the motor system to retract – thus potentially influencing the effect for hand-related nouns. Accordingly, the interaction between Noun type and Adjective type was of most interest, but no such interaction effect occurred, and no main effect for Adjective type was found either. Subsequently, it was posited that perhaps the lack of an interaction effect was due to the shallow levels of processing required to undertake the GoSignal task.

Thereafter, the potential effect of Adjective type on hand responses to Noun type was tested using tasks that required slightly deeper and much deeper levels of processing, respectively – a lexical decision task (LDT) and a semantic decision task (SDT). In both the LDT and the SDT, the same adjective/noun stimuli were used as in the GoSignal experiment, however, the tasks specifics in these experiments differed to the GoSignal task. Specifically, the LDT required participants to decide whether or not a presented stimulus was a word, whereas the SDT required a decision as to whether or not the stimulus was not an animal word. In both the LDT and the SDT, a significant main effect for Noun type was found but in the opposite direction to the effect in the GoSignal task (i.e., it was slower). A significant main effect for Adjective type was also found in both experiments – negative and non-negative adjectives elicited quicker hand RTs than trials with pseudo adjectives. Neither the LDT or the SDT found a significant interaction effect between Adjective type and Noun type; thus, as with the GoSignal experiment, Adjective type did not modify hand responses to Noun type.

Chapter 4 in the current thesis examined the potential effect of *age of acquisition* (AoA) on previous findings that were in line with theories of language embodiment. Explicitly, AoA reflects to the period within which a word, phrase, skill, or concept has been learned (Brysbaert et al., 2000; Catling & Elsherif., 2020; Ellis et al., 2010). Typically, early AoA relates to the period before aged 6/7 years old, while late AoA relates to the period after aged 6/7 years old, and early AoA has often been shown to have an RT advantage over late AoA (see Arnon et al., 2017; Catling et al., 2013; Ellis et al., 2010; Stadthagen-Gonzalez et al., 2004). To ascertain the potential impact of AoA on previous findings, Chapter 4 reviewed a subsection of embodiment studies from the last 22 years (i.e., 2000-2022) on the *PubMed* database to first establish whether or not AoA had been considered as a potential factor. If AoA was not considered, the available stimuli from each study were compared against an established set of AoA norms (i.e., typically, Kuperman et al `s 2012 AoA ratings) to try to test whether or not the AoA omission could have been a potential confounding variable in that study. Here, it was found that only 1/15 studies reviewed had controlled for AoA. Moreover, in 6/14 remining studies, when the same contrasts were run but AoA was included as a dependent variable, a significant main effect was found. Thus, findings from many studies reviewed could have been influenced, or indeed driven by, AoA.

Chapter 5 sought to build on these earlier findings by testing the impact of AoA on motor responses more directly. Here, an LDT was constructed and presented to a sample of younger participants (i.e., 18-44 years old). The real words used were grouped via whether they were hand related or non-hand related, early acquired or late acquired, high in frequency or low in frequency – thus, AoA was controlled for, and the experiment found many interesting results. Of most interest was the significant interaction effect between AoA and Hand Relatedness. Here, we found a difference in the pattern of interaction between Hand Relatedness and early AoA and Hand Relatedness and late AoA. Specifically, in relation to early acquired words, hand-related stimuli elicited quicker hand RTs than non-hand related stimuli. However, the opposite pattern was found for late acquired words, as hand-related words learned after approximately 7 years old elicited slower hand RTs than non-hand related words learned during the same period. Overall, this difference in the effect of Hand Relatedness within early acquired and late acquired categories suggests that in a younger sample, the degree to which motor-related language influenced motor performance depended upon the age at which the motor language had been learned.

We ran the same experiment with an older adult group and also found some interesting results. For example, as with the younger participants, we found no significant main effect for Hand Relatedness. However, in contrast to the younger participant experiment, we found no significant interaction effect between AoA and Hand Relatedness, though the pattern of early learned and late hand related effects were in the same direction. The other effect of interest in the older adult experiment was a significant interaction effect between Frequency and Hand Relatedness. Specifically, the older sample analysis showed that hand-related stimuli were only advantageous over non-hand related stimuli during low frequency conditions. Thus, overall, our older adult LDT only found support for the influence of motor-related language on motor activity in relation to low frequency word conditions. Coupled with the results from our younger participant experiment, it suggests that controlling for AoA can modify findings that typify embodied language studies.

Chapter 6 aimed to further explore the neural basis of motor-related language. To achieve this, an EEG experiment was conducted requiring participants to process a prime word (i.e., a noun) followed by a target word (i.e., a different noun). In each instance, the prime word bore some relation to the target – either motor (e.g., *pea, pill*), semantic (e.g., *chemist, pill*), unrelated (e.g., *wardrobe, pill*), or pseudo (e.g., *rosw, pill*). Many previous studies had found that relative to unrelated pairings, processing semantically related prime/target pairings elicited a reduced cluster of brain activity known as the N400 component (e.g., Kappenman et al., 2021). Chapter 6 tested whether or not a reduced N400 could also be elicited whilst processing motor-related vs. unrelated prime/target pairings.

However, in relation to mean amplitude, Chapter 6 found no significant main effect for prime condition. In addition, no significant differences were observed between any of the prime conditions; thus, we did not observe a semantic vs. unrelated prime difference nor did we observe a motor vs. unrelated prime difference. For peak latency, there was also no significant main effect for prime condition. As before, no differences were observed between prime conditions either.

7.2 Potential implications and future directions

The findings from Chapter 3 have many potential implications for embodied language research and researchers. For example, taken together, all three adjective/noun experiments found a significant main effect for Hand Relatedness, in that processing hand-related nouns modified subsequent hand motor responses relative to processing non-hand related nouns. Thus, our findings add to the large body of overall evidence which has shown that processing nouns referring to manipulable objects (e.g., *a pencil*) activates and uses the motor system. Further, the findings add to the wealth of specific behavioural evidence which has found that processing hand-related nouns can also modify subsequent hand motor responses (see Buccino et al., 2018; Gough et al., 2013; Marino et al., 2011, 2014). Previously, it had been posited that this occurs because the hand region of the motor system is causally involved in processing hand-related stimuli (see General introduction); thus. processing a hand-related stimulus activates and uses the hand motor area. If a participant needs to use their hand to perform a subsequent task, the prior hand motor activation can either facilitate (i.e., speed up) or inhibit (i.e., slow down) the subsequent hand response – which was confirmed by all experiments in Chapter 3.

Moreover, in Chapter 3, differences in facilitation (i.e., the GoSignal experiment) and inhibition (i.e., the LDT and the SDT) of RTs during hand-related noun processing were most probably due to task demands. As outlined, the GoSignal task instructed participants to respond between 0-200 ms after the noun was presented, whereas the LDT and SDT allowed participants to respond on their own time (relative to recognising a real word and a non-animal word, respectively). Plausibly, these factors could have influenced the quicker and slower hand RTs during hand noun processing in the different experiments. The incremental differences in mean times across experiments also shows the influence that levels of processing can have, as average RTs increased when level of processing increased (i.e., GoSignal-LDT-SDT). However, it is still noteworthy that in three different tasks – which required three different levels of processing – hand-related nouns excited the motor system, regardless of task. Phrased another way, a task requiring a shallow, bottom-up level of processing (i.e., GoSignal experiment), influenced hand motor responses as did tasks requiring deeper levels of processing (i.e., LDT and SDT). Overall, this suggests that motor activity during hand-related noun processing could be automatic – which, on the one hand, supports the claim that motor excitability during language processing does not dependent upon task demands. However, on the other hand, whether or not motor excitability impedes or facilitates subsequent motor behaviour does appear to be due to task demands. Collectively, the findings here on hand-related nouns support the view that processing a noun referring to an object upon which the hand can act activates and uses the hand motor area – a claim which is at the forefront of embodied language theories.

However, none of the experiments from Chapter 3 found that hand responses to Noun type were influenced by preceding Adjective type; thus, we cannot add to previous findings on the embodiment of adjectives (i.e., Garafola et al., 2021; Gough et al., 2012) – though, our methods and stimuli did differ to both experiments. Accordingly, further research is needed to try to establish the representational nature of adjectives that describe properties related to motor activity. Additionally, in our LDT and SDT, both real Adjective types appear to have primed subsequent responses to Noun type – regardless of the properties of the Noun type. This highlights the potential difficulty with priming and levels of processing, which future studies will need to address. Future studies could also group nouns based upon whether or not they describe objects that require a power grip or a precision grip (as with Glover et al., 2004; Koester & Schack, 2016) and try to find suitable adjective types for both noun groups. Interestingly, using TMS, a Gough et al. study (2012) found significantly greater MEPs in grasping muscles in participants` right hand while nouns referring to tools were processed vs. natural hand-related and non-hand related nouns. However, Chapter 3 did not group nouns in this manner, and a future study should definitely consider this option. Additionally, some of our nouns referred to food-related items (e.g., *banana*), and in different conditions, this word was preceded by an adjective such as *rotten* or *fresh*. It is possible, though, that words such as *rotten* and *banana* are just as related or more related to food/eating than to grasping (Lynott et al., 2020); thus, processing these words could have activated face sensorimotor regions to a greater degree than hand regions. A future fMRI study could try to shed some light on this potential confound by examining the neural basis of potentially food-related (yet graspable) vs. purely hand-related nouns. For now, Chapter 3 finds support for the embodiment of nouns but not for the embodiment of adjectives. It also highlights the impact that task demands can have on language processing and subsequent motor performance.

Potentially, the findings from Chapters 4 and 5 are more problematic for embodied theories of language. For example, the Chapter 4 review found that many previous findings that fall in line with embodied theories had not considered the potential influence of AoA. In addition, when the same contrasts were performed with AoA included as a potential factor, we found that over 40% of studies` findings (i.e., 6/14) could have been influenced by AoA. Chapter 5 built upon these findings by testing the effect of AoA on hand-related language directly, and it was found that for younger participants, the effect for Hand relatedness only applied to early learned language. Furthermore, it was found that late hand-related words elicited significantly slower hand-related effects. Interestingly, the same pattern was found for older adults, but this was not significant – whereas the older adult work did find a main effect for Hand Relatedness relative to low frequency words only. Also of note was that a significant main effect for AoA was observed in the older sample – overall, early learned words elicited significantly quicker hand RTs than late learned words regardless of whether they were hand or non-hand related.

At the very least, the findings from Chapters 4 and 5 suggest that AoA should be considered as a variable in future motor-related language research. Though sometimes problematic, there are many possible methods of grouping stimuli via whether they are early or late learned (see Chapter 4, Section 4.3). However, potentially, the current AoA findings imply that the motor-related effects that have typified much embodied language research could be due to AoA – which calls at least some existing literature into question. Future work will need to consider this caveat when testing the effect of motor-related language on motor activity, and consideration should be given to the age of the sample, too. Based upon the current findings, it could be claimed late learned hand-related language is not embodied, and the effect for early hand-related language also depends upon the age of the participants. These issues will need to be disentangled in future work if researchers wish to state that late learned hand-related language is embodied and that embodiment persists across the lifespan.

One suggestion for a future study would be to examine the neural basis of early and late learned hand-related and non-hand related language using fMRI. As discussed in the general introduction, fMRI can be a useful measure of establishing which brain areas are involved in a given task. Moreover, ample studies have shown that processing motor-related stimuli is associated with a mirroring circuit in parietal and motor regions; thus, if late learned hand-related language is embodied, it should result in increased fMRI activations in these regions while corresponding stimuli are processed. Alternatively, TMS could be used to stimulate motor cortex during late and early language processing, and researchers could examine the resulting arm/hand MEPs. If late learned hand-related language modifies MEPs, then one could conclude that late learned hand-related language also resides in the sensory and motor systems. Additionally, rTMS could be used to temporality lesion left primary motor cortex, and late learned hand-related and non-hand related language could be presented. Difficulties processing late learned hand-related language in these circumstances would suggest that left primary motor cortex is causally involved in processing associated stimuli. However, currently, our work suggests that hand relatedness (i.e., different effects of hand vs. non hand stimuli) could be due to the age at which the hand language has been learned (i.e., AoA). Interestingly, a retrospective comparison of the hand-related vs. non-hand related noun stimuli from Chapter 3 (adjective/noun experiments) showed that they were actually balanced for AoA. Time constraints meant that stimuli from Chapter 6 (the EEG and accompanying behavioural experiment) were not checked.

Furthermore, the Chapter 5 findings suggest that the interaction between early AoA and Hand-relatedness differs by age group. Therefore, it is not quite clear if the majority of current embodied language findings would be observed if tested with older samples. However, it is worth repeating that our older adult sample was recruited online, and we had no means of verifying factors like age or gender, though they were recorded on Qualtrics. In addition, this experiment was primarily comprised of males, so a future study should aim to test a more balanced sample. All things considered, though, future work should aim to further test the effect of motor-related language on samples aged 50+ to establish more about embodied language across the lifespan.

The findings from Chapter 6 were a little unexpected. For example, while the effect of hand-related word pairings on the N400 ERP component had not been tested previously, the difference in N400 amplitude between semantic and unrelated pairings had. Typically, previous studies had found that semantic pairings (e.g., *bread, butter*) elicited reduced N400 amplitude in comparison with unrelated pairings (e.g., *bread, tower*); thus, a similar effect was expected here. No such effect was observed, however, and it is quite probable that this is due to our design. As discussed, our work was based upon the Kappenman et al. (2021) study, and our timings and order of stimuli were adapted from that work. We did not employ the same semantic task, though, and our sample ($N = 24$) was also smaller than theirs ($N = 39$). Previous EEG experiments also found that it was congruency between motor-related language and a motor response that elicited reduced N400 activity (see Al-Azary et al., 2022; Cervetto et al., 2021), whereas motor responses to stimuli were not required in the present work. Furthermore, our experiment contained two extra conditions, which meant that participants saw the target word in twice as many contexts. Finally, the EEG work in Chapter 6 also only examined amplitude and latency at electrode Cz, whereas Kappenman et al. (2021) analysed activity at many other electrode sites (e.g., CPz, Fz, F3, F4, C3, C4). Though, it cannot be overlooked that the experiment did not find a motor nor a semantic effect, it is plausible that the above issues played a major role. Future work should take these potential confounds into account before attempting a similar N400 experiment.

7.3 Potential applications

There are many potential applications that arise from the current thesis`s findings. For example, the results in Chapter 3 provide further support for the claim that processing hand-related nouns activates and uses the hand motor regions, which suggests a close link between motor language and sensorimotor experience. Additionally, though not tested in the same experiment, much prior research has also shown that processing hand-related verbs activates and uses the same sensorimotor regions as hand-related nouns (see General Introduction). Knowing that processing verbs and nouns (and possibly adjectives) is related to sensorimotor activity could have many beneficial applications. For example, deficits in language processing are associated with subsequent behavioural issues (Miller & Wagstaff, 2011; Petersen et al., 2013). Moreover, these issues can manifest internally (e.g., anxiety) and/or externally (e.g., aggression, hyperactivity) (Curtis et al., 2018); thus, establishing viable interventions for affected people is of great potential utility. Accordingly, designing language interventions based around enhancing sensorimotor experience could improve outcomes for many.

Relatedly, research has already shown that tactile interventions – such as interacting with and separating objects – can enhance the corresponding words` representations for people with dyslexia and other learning difficulties (Supriatna & Ediyanto, 2021). In addition, a study by Zuccarini et al (2018) found that early object exploration was correlated to later language ability. Specifically, the study found that children’s oral and motor interactions with objects at six months old was associated with their word comprehension, gesture, and vocal production at twelve months old, respectively. Zuccarini et al (2018) further showed that early object exploration behaviours were predictive of later linguistic capabilities across a cohort of premature infants. The current findings, which suggest that processing words referring to objects is closely related to the actual object, provides further support for the continued use of physical sensorimotor interventions for those with language-related issues.

The current AoA findings have many potential applications, too, as they once again highlight the advantage of language learned in the early years (i.e., up until aged 7 years old) relative to language learned after this timepoint (i.e., from aged 7 years old onwards). The findings with our younger adult group provided a further, indirect example of the advantage of early manual exploration for language processing. Specifically, the experiment found that early learned hand-related words were advantageous relative to early learned non-hand related words, whereas late learned hand-related words were disadvantageous relative to late learned non-hand related words. Though, potentially, this suggests that it may be only early learned language that is embodied – which language researchers will need to address – it also implies that early hand-related language is related to the corresponding hand motor activity. Again, this finding provides added support for those wishing to provide manual interventions to young people with language issues.

Additionally, the older group findings showed that language learned before aged 7 years old was still advantageous relative to language learned after this period – even in participants who were aged between 50-65 years old. This finding has many potential applications in educational and health-related settings. For example, in 2020, it was estimated that there was typically one person in each Irish primary school living in the care system and potentially up to five children in each secondary school who were in care; these young people also tend to be more likely to receive school suspensions and expulsions – often due to behavioural issues (EPIC, 2020). Though schools have been criticised for not providing the extra emotional and psychological support to deal with those experiencing trauma (Hughes et al., 2015), educators and care workers should also consider the possibility that the problematic behaviours could reflect underlying language-related issues. For instance, it is well known that many in the care system have undergone some form of trauma (Hughes et al., 2015). Conceivably, this trauma could have impacted on a care user`s early language learning, which could result in deficits and thus frustration in academic settings. Accordingly, in addition to providing appropriate emotional and psychological support in schools and care settings, language-based interventions should be offered. Moreover, a slightly adjusted curriculum could be designed to suit those who missed out on some aspects of language learning during the period up until 7 years old.

7.4 Limitations and considerations

One of the major limitations of the current thesis relates to Covid-19 restrictions in Ireland. Specifically, in March 2020, higher education institutions such as MU were forced to close down. Though Government plans were made to reopen university settings at various stages, the spread of Covid-19 meant that Ireland more or less remained in lockdown until September 2021 (Department of Health, 2022). Accordingly, all in-person research had to cease during this period, and alternative plans for future research had to be fostered and employed. For the current thesis, this meant placing some existing research on hold and adjusting future plans to coincide with ongoing circumstances.

Explicitly, Experiment 3.3 (SDT – see Chapter 3), which had tested 30 participants in person by March 2020 had to be placed on hold. The remaining participants were not tested until October/November 2021; though, as there were only 10 left to test, no major issues ensued. Experiment 3.2 (also from Chapter 3), which was due to be run in person, had to be modified to run online. Additionally, Experiment 5.2 (older adult LDT – see Chapter 5) had to be designed with an online audience in mind. From a design perspective, this meant learning a new experiment building software program (i.e., *PsychoPy*) and linking to this via *Qualtrics*. Fortunately, neither software program proved overly difficult to navigate.

There were also no major issues with running Experiment 3.2 online, though some experimental control was potentially relinquished, (see Chapter 2). Actually, using an online platform for this experiment allowed for a much greater number of participants (i.e., N = 130) than would have been tested in person. However, converting the older adult experiment (i.e., Experiment 5.2) to an online format raised slightly more issues that needed to be considered. For a start, it meant that it would not be an option to meet and greet the older sample and fully explain the nature of the task they would undertake. This meant that it could be problematic to test a group older than 65 years old, as it would not be possible to guide them through a practice run and remain with them for a few minutes to establish whether or not they could negotiate the task. It also meant not being able to discuss factors such as whether or not any participant experienced motor-related issues, which seems more probable in over 65s. Though it was also not possible to apply these criteria with those who actually partook in the older adult experiment (and the LDT experiment online), associated demographic data were recorded on Qualtrics (i.e., motor issues etc.). All things considered, testing a sample aged between 50-65 via an online experiment seemed slightly less problematic than testing an older group aged 65+. However, recruiting participants online brought extra potential issues and limitations.

As outlined, many who partook in the online LDT experiment were part of the MU Department of Psychology participant pool – though, some others were recruited from *LinkedIn* and *Reddit*. However, the majority who partook in the older adult experiment were taken from these two internet platforms (a few others were recruited by poster advertisement in MU), as the current author had no access to older adult groups via any other means. Additionally, the current thesis was not in receipt of any funding, so mediums like *LinkedIn* and *Reddit* had to be utilised to recruit participants. With these participants, there was no method of verifying whether or not they fitted the age criteria (i.e., were aged 50-65), and there was no method of accounting for factors like gender, which could be achieved when recruiting from the participant pool. Resultingly, the older adult LDT sample was predominately male (i.e., 70%), which is a potential limitation that arose from using online forums. There are methods to account for gender and age balancing, but these are not accessible to all.

For example, recruiting mediums like *Prolific* and *Amazon Mechanical Turk (MTurk)* allow for grouping participants via age and gender, but both require a fee to be paid to participants and to the platform provider (Peer et al., 2021). Moreover, *Prolific* requires a minimum fee to be paid to participants – depending upon time requirements and choice of region – whereas *MTurk* allows the recruiter to set the fee (Peer et al., 2021). Regardless, recruitment on both platforms requires some type of funding, which is a potential limitation and disadvantage for those without. Alternatively, those without funding have to use mediums such as the ones described above.

Covid-19 restrictions also highlighted the need for research to be adaptable and transferable to online audiences. Accordingly, the current climate of accessible computer programs such as *PsychoPy* experiments hosted on *Pavlovia.org* (https://pavlovia.org/) allow for many behavioural experiments to be run online – the results of which can potentially add to existing theories. However, as discussed throughout this thesis, embodied theories of language are supported by neural and brain stimulation studies in addition to behavioural studies, and it is currently not possible to utilise the former two with online audiences. Though restrictions have ceased, it is not inconceivable that another pandemic or similar event could emerge; thus, academics and scientists need to start thinking about possible ways to advance research conducted online by developing more than just behavioural methods. Otherwise, the evidence used to support/oppose hypotheses, and to design interventions, will be much narrower than it is currently. Essentially, data would be of a much lesser quality if only behavioural methods can be used in non-face to face situations.

7.5 Conclusions and current stance on the embodied continuum

Overall, the current thesis aimed to further test theories of embodied language. Relatedly, Chapter 3 examined the effect of processing a much lesser studied word category (i.e., adjectives) on motor responses, and the impact of differing task requirements on processing was tested, too. Moreover, the potential influence of *age of acquisition* (AoA) on previous embodied language research was examined in Chapter 4, while Chapter 5 tested the direct impact of AoA on motor responses to motor and non-motor language. Using EEG, Chapter 6 tested the effect of motor-related language on the N400 brain component. Taken together, the findings from the current thesis can help to add to the embodied continuum debate.

The Meteyard et al. (2012) review proposed that embodied language theories fall along a continuum ranging from *unembodied*, to *secondary embodiment*, to *weak embodiment*, and *strong embodiment*. Essentially, unembodied theories are amodal and posit that neural processing of language does not actively involve sensory and motor areas, as word meaning is derived via relations with other words (see Bedny & Caramazza, 2011; Fodor & Pylyshyn, 1988). Theories of secondary embodiment claim that the relationship between sensorimotor content and language representation is purely associative – classic language areas are causally involved in language processing while sensory and motor areas are activated passively (see Mahon & Caramazza, 2008). The findings on noun processing from Chapter 3 in the current thesis (and much existing research – see General introduction) do not support either of these viewpoints. Specifically, the Chapter 3 findings showed that processing nouns referring to hand-related objects (e.g., *pot*) modified subsequent hand activity relative to non-hand related nouns (e.g., *hill*). This suggests that the sensorimotor hand regions could be functionally involved in processing hand-related nouns, and the representation of the word is closely related to the object described. Additionally, while it does appear that task demands can determine the nature of the hand modification, hand-related nouns still impacted hand activity across a range of different tasks with different levels of processing. All things considered, these findings suggest that the relationship between sensorimotor activity and language representation is more than associative and passive.

Meteyard et al. (2012) also proposed that the weak embodiment view posits that processing sensory and motor information partially depends upon the sensory and motor brain areas, and these brain areas assist in semantically integrating information to facilitate a more complete representation (see Vigliocco et al., 2004). In contrast, the strong embodiment view claims that semantic processing is completely dependent upon the sensory and motor areas; central to this viewpoint is the claim that direct experience of a word`s referent is always simulated in sensory and motor systems (Barsalou, 1999). In one sense, the findings from the current thesis (particularly with nouns in Chapter 3) appear to lean towards the strong embodiment point of view; direct experience of a word`s referent is automatically simulated in sensory and motor systems – hence the hand modification in all tasks in the current work while hand nouns were processed. However, the lack of an interaction effect in Chapter 3 while processing different Adjective types suggests that automatic sensory and motor activations may not always occur in motor language processing and may be due to task demands, which does not align with the strong embodied view.

Moreover, the Chapter 5 experiments showed that AoA can modify (Experiment 5.1) and even eliminate (Experiment 5.2) the typical hand-related effects in language processing and that this can also depend upon age group – all of which suggests that there may be other factors at play. Chapter 6 also found that processing hand-related language did not modify

N400 brain activity (i.e., reduce) relative to non-hand related language. Thus, it is not possible for the current thesis to state that sensory and motor activity is always activated in language processing – as per the strong embodiment account. To support the strong viewpoint, future work would need to show that adjectives related to approaching (e.g., *soft*) and avoiding objects (e.g., *sharp*) automatically activates and uses the corresponding hand motor regions. Additionally, researchers would need to demonstrate that hand-related word effects can still be observed when AoA is accounted for and that language learned after 7 years old uses the motor regions, too. Moreover, the findings would need to extend to samples over 50 years old, and researchers would also need to able to show that motor-related language impacts upon the N400 brain wave.

Presently, the current findings seem to reside somewhere between the weak and the strong embodied viewpoints. We have found some support for the strong view, potentially, by showing that hand-related nouns modified hand motor activity across a range of different tasks. However, it is not clear if the lack of motor activity during adjective processing is the result of task demands and/or if it means that processing some motor language only partially depends upon the sensory and motor brain areas – as per the weak embodied view (see Vigliocco et al., 2004). Future researchers will need to show that typical motor effects, if any, are not due to AoA – by controlling for the variable – or influenced by the sample`s age. The current thesis has found that both these factors have an influence – again, suggesting that sensorimotor regions are not necessarily automatically activated in motor-related language processing. The lack of a motor-language related reduction on the N400 seems to support this latter proposition. Future work could run the same EEG experiment using the suggested modifications; results could then be placed along the embodied continuum.

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Appendices

Appendix A: Edinburgh handedness Inventory

Appendix B: Adjective/noun stimuli from Chapter 3

Appendix C: Studies examined in the Chapter 4 AoA review

Appendix D: Hand related/Frequency/AoA stimuli used in Chapter 5

Appendix E: Target/prime stimuli used in Chapter 6

Appendix A

Handedness Inventory

Participant code

Have you ever had any tendency to left-handedness? YES NO

Please write your preferences in the use of hands in the following tasks by putting a + in the appropriate column. **Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If for any action you are really indifferent put + in both columns.

Some of the tasks need both hands. In these cases the part of the task, or object, for which the hand you use is being asked is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have never used the object or done the task.

		R	L
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Comb		
6	Toothbrush		
7	Knife (on its own, without a fork)		
8	Spoon		
9	Hammer		
10	Screwdriver		
11	Tennis racket		
12	Knife (with a fork)		
13	Cricket bat (lower hand)		
14	Golf club (lower hand)		
15	Broom (upper hand)		
16	Rake (upper hand)		
17	Striking match (match, not the box)		
18	Opening box or jar (lid, not the box or jar)		
19	Dealing cards (card being dealt, not the pack)		
20	Threading needle (needle or thread depending on which is moved)		
40	Which foot do you prefer to kick with?		
41	Which eye do you use when only using one (in a camera or telescope)?		

LANGUAGE EXPERIENCE

Is English your first language?________ If not: What is your native language? _____

At what age did you learn English? ________

What other languages do you speak?

(Please indicate if fluent/good/minimal.)

Appendix B

Adjective/noun stimuli used in Chapter 3

Negative adjective/hand noun	**Positive adjective/hand noun**
Barbed wire	Brown wire
Smashed plate	Plastic plate
Jagged knife	Clean knife
Rotten banana	Fresh banana
Dirty shirt	Silk shirt
Broken glass	Large glass
Filthy boot	Leather boot
Boiling pot	Empty pot
Cracked bulb	Bright bulb
Spiky rose	Beautiful rose
Burning stick	Walking stick
Sharp scissors	Craft scissors
Rusty chain	Shiny chain
Thorny stem	Long stem
Shattered cup	China cup
Bloody bandage	Cotton bandage
Mouldy bread	Tasty bread
Used tissue	White tissue
Hot iron	Small iron
Live cable	Grey cable

Negative adjective/non-hand noun	**Positive adjective/non-hand noun**
Loud sound	Soft sound
Awful holiday	Annual holiday
Dark cloud	Distant cloud
Poor practice	Correct practice
Shocking event	Special event
Freezing ocean	Calm ocean
Impossible route	Exact route
Heavy rain	Gentle rain
Messy kitchen	Modern kitchen
Unhealthy marriage	Strong marriage
Anxious wait	Short wait
Terrible concert	Rock concert
Bad news	Excellent news
Bitter autumn	Delightful autumn
Steep hill	Rolling hill
Tough exercise	Basic exercise
Noisy traffic	Smooth traffic
Difficult exam	Simple exam
Foul smell	Wonderful smell
Wet day	Magnificent day

Appendix C

Studies examined in the AoA review

- Sokoliuk et al. (2013) conducted an EEG study which measured ERPs during motor verb (e.g., *grab*) and non-motor verb processing (e.g., *fail*). Within a 164–203 ms post-stimulus presentation time-window, the study found significant differences between ERPs elicited by the two verb types. AoA was controlled in this study – using the Kuperman et al. (2012) norms.

  https://pubmed.ncbi.nlm.nih.gov/31391537/

- Moseley & Pulvermüller (2014) used fMRI to examine the neural basis of concrete verbs, concrete nouns, abstract verbs, and abstract nouns and found that concrete verbs and nouns both activated inferior frontal and primary motor regions. Further, the study found that concrete verbs elicited greater central motor activations, whereas concrete nouns excited inferior frontal regions more (Note; some concrete verbs described hand actions, and others described foot actions). Neural activity in motor and premotor regions did not differ while processing abstract nouns and verbs. Our analysis tested whether or not concrete verb vs. concrete noun activations could have resulted from AoA. An AoA value was established for each word; verbs and nouns were compared with AoA score as the outcome variable. The analysis found a significant main effect (F (1, 78) = 14.4, $p = 0.001$, $\eta^2 = 0.16$).

  (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4029073/

- Mollo et al. (2016) examined hand and foot RTs while hand- and foot-related words were processed; the study found significantly quicker hand than foot responses to hand-related vs. foot-related stimuli. Our analysis established an AoA value for hand and foot words and performed a between-groups analysis with AoA score as the outcome variable. Here, no significant main effect was found (*F* (1, 78) = 0.53 *p* = 0.46). https://core.ac.uk/download/pdf/81145672.pdf

- Kemmerer (2008) used fMRI to measure participants` cortical activity while they made semantic decisions about five different classes of verbs. They found that running verbs activated foot premotor and motor regions, while verbs related to hitting and cutting activated the arm and hand premotor and motor regions, respectively. Speaking verbs and change of state verbs did not activate left premotor or primary motor regions. To test whether or not findings could have been due to AoA, our analysis assigned each word an AoA value. A between-groups ANOVA was conducted with AoA score as the outcome variable – this showed that AoA probably did not influence findings (*F* (4, 101) = 0.72, *p* = 0.57). https://www.sciencedirect.com/science/article/pii/S0093934X07002611

- Miller et al. (2018) used both EEG and behavioural measures, across a series of experiments, to compare hand and foot responses while hand- and foot-related stimuli were processed – experiments 1 and 3 used the same hand- vs. foot-related stimuli. For our analysis. hand- and foot-related words from experiments 1 and 3 were compared with AoA value as the outcome variable. This analysis found no significant main effect (*F* (1, 182) = 2.6, *p* = 0.11). Similarly, there was no AoA effect for stimuli used in experiment 2 (*F* (1, 58) = 1.3 *p* = 0.25) and experiments 4 and 5 (*F* (1, 182) = 2.53, *p* = 0.11). https://pubmed.ncbi.nlm.nih.gov/28933898/

- Zhang et al. (2016) used an RT task to examine hand and foot RTs to hand- and foot-related nouns and pictures. The study found that hand RTs were quicker than foot RTs during the processing of hand- and foot-related words. Our analysis assigned the hand and foot words an AoA value, and using a between-groups ANOVA, it was found that the dataset did not differ by AoA (*F* (1, 14) = 0.07, *p* = 0.9).

  https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4879702/pdf/srep26806.

- Buccino et al. (2018) compared hand RTs to hand- and non-hand related nouns and pictures (in Parkinson`s disease patients and controls) and found that controls had significantly slower hand RTs while processing hand-related stimuli. Our analysis established an AoA value for hand- and non-hand related words and tested whether or not differences could have been due to AoA. A between-groups ANOVA found no significant main effect (*F* (1, 36) = 0.86, *p* = 0.36).

  https://pubmed.ncbi.nlm.nih.gov/28413070/

- Using TMS, Gough et al. (2012) measured MEPs while hand- and non-hand related natural and artefact nouns were processed. MEPs were examined from the first dorsal interosseous (FDI) muscle in participants` right hand – associated with grasping actions. The results showed significantly greater MEPs while nouns referring to tools were processed (Gough et al., 2012). Our analysis established an AoA value for each word in the four categories, and a between-groups ANOVA was conducted with AoA as a dependent variable, which revealed a significant main effect (*F* (3, 30) = 7.3, *p* = <.001, η^2 = 0.42).

  https://pubmed.ncbi.nlm.nih.gov/22044649/

- Dreyer and Pulvermüller (2018) examined the neural basis of abstract emotional, abstract mental, food, and tool nouns and found that different word categories elicited different neural activations (e.g., food nouns activated face motor areas; hand nouns activated precentral and premotor regions). Our analysis established an AoA value for each word and conducted a between-groups ANOVA which tested for AoA differences between the four word categories. Here, a significant main effect was found (F (3, 102) = 27.5, $p < .001$, $\eta^2 = .45$).

  https://pubmed.ncbi.nlm.nih.gov/29455946/

- Dreyer et al. (2015) conducted a lexical decision task (LDT) with patients and controls; both groups processed tool, food, animal, and abstract emotional nouns in addition to hand, face, leg, and abstract verbs. The results showed that controls had significantly longer RTs while tool nouns and abstract emotional nouns were processed. Additionally, hand-related verbs elicited significantly quicker hand RTs relative to the other verb categories (Note; verb frequencies were greater than for nouns, and no cross-lexical category balancing was performed – i.e., verb frequencies were not compared with noun frequencies). Using a between-groups ANOVA, we tested for AoA differences between the four noun categories; here, a significant main effect was found F (3, 141) = 21.9, $p < .001$, $\eta^2 = .31$), suggesting that the finding could have resulted from AoA. The same process was applied to the different verb types; this analysis also revealed a significant main effect (F (3, 155) = 5.4, $p < .002$, $\eta^2 = .10$).

  https://pubmed.ncbi.nlm.nih.gov/26617535/

- Dreyer et al. (2020) conducted a later study with a larger patient group (and controls) using the same stimuli and LDT as in the 2015 study. In this later experiment, only

RTs to food, animal, and tool nouns were examined. Using the same noun grouping process as above with AoA score as the outcome variable, our analysis found no significant main effect (*F* (2, 109) = 0.3, *p* = 0.70).

https://pubmed.ncbi.nlm.nih.gov/32061830/

- Willems et al. (2010) ran an fMRI study to test whether or not processing hand-related and non-hand related verbs in an LDT activated the same neural regions as during motor imagery. The study found greater left premotor activity as manual compared with non-manual verbs were processed in during both the LDT and imagery task. It was also found that regions of premotor and primary motor cortex active during imagery were not active during LDT. In contrast, premotor and primary motor cortex regions of interest (ROIs) which showed effector-specific activity during LDT showed no effector-specific activity during imagery. Our analysis established an AoA value for each hand-related and non-hand related verb. A between-groups ANOVA was then conducted with AoA value as a dependent variable – this analysis found no significant main effect (*F* (1, 92) = 1.33, *p* = 0.25).

  https://pubmed.ncbi.nlm.nih.gov/19925195/

- Willems et al. (2010) conducted another study to test for motor differences and hemispheric differences between left- and right-handers as they underwent the same procedures outlined above. Here, it was found that left-handers had greater activations in right motor regions for manual vs. non-manual verbs, whereas righthanders had greater activity in left motor regions. As with the previous result, these differences do not appear to have been driven by AoA (*F* (1, 92) = 1.33, *p* = 0.25)

  https://pubmed.ncbi.nlm.nih.gov/20424025/

- van Dam et al. (2010) conducted an fMRI study to test participants` processing of basic verbs (e.g., *to clean*), specific verbs (e.g., *to wipe*), and abstract verbs (e.g., *to enjoy*). The study found that relative to abstract verbs, both manual verb types (basic + subordinate) elicited greater activity in areas such as the left inferior parietal lobule (IPL) and left postcentral gyrus. Our analysis established an AoA value for each verb, and a between-groups ANOVA was conducted to test for a potential effect of AoA. Here, a significant main effect was found (F (1, 76) = 14.3, p < .001, η^2 = .16). Additionally, the van Dam et al. (2010) study found significantly greater activity in the IPL for specific verb processing vs. basic verb processing. Our analysis compared the basic vs. specific verbs but used AoA value as the outcome variable. This analysis found no significant main effect (F (1, 50) = 0.20, p = 0.6)

  https://pubmed.ncbi.nlm.nih.gov/20619347/

- van Dam et al. (2012) ran a later fMRI study to try to build upon their earlier 2010 findings. Here, participants` neural activity was examined as they processed action-colour words (e.g., *boxing glove*, *tennis ball*) and abstract words (e.g., *magic*, *justice*). The study found that action-colour words elicited greater activity in areas such as the bilateral superior temporal gyrus (STG), mid temporal gyrus (MTG), superior frontal gyrus, and the cerebellum. Our analysis established an AoA value for each action-colour and abstract word, and we conducted a between-groups ANOVA with AoA score as a dependent variable. Here, we found a significant main effect (F (1, 40) = 22.9, p < .001, η^2 = .37).

  https://pubmed.ncbi.nlm.nih.gov/22721380/

Appendix D

Stimuli used in Chapter 5

Early/Hand/High Freq.	**Early/Hand/Low Freq.**
Break	Torch
Hold	Peg
Trace	Sack
Cover	Cloak
Shut	Scarf
Apple	Coin
Hit	Umbrella
Bring	Clap
Brush	Rip
Coat	Scribble
Shell	Salute
Lettuce	Dig
Pencil	Bucket
Soap	Hammer
Bag	Smash

Early/Non-Hand/High Freq.	**Early/Non-Hand/Low Freq.**
Garage	Zoo
Forest	Cough
Secret	Squeak
Guess	Hop

Value

Yell

Star

Lick

Witch

Chimney

Early/Non-Hand/High Freq. (cont.)

Slip

Sentence

Sing

Moon

Stream

Cry

Test

Breath

Early/Non-Hand/Low Freq. (cont.)

Goat

Exit

Infant

Seaside

Mist

Buzz

Trot

Pond

Late/Hand/High Freq.

Strike

Magazine

Serve

Spanner

Attach

Grasp

File

Pitcher

Coral

Toss

Late/Hand/Low Freq.

Clove

Passport

Shred

Weld

Stitch

Flannel

Flyer

Bind

Stab

Pendant

Gesture	Chisel
Combine	Twine
Rifle	Haul
Seize	Clench
Weapon	Moccasin

Late/Non-Hand/High Freq.	**Late/Non-Hand/Low Freq.**
Persuade	Demise
Phrase	Feat
Source	Revise
Locate	Assess
Expert	Whim
Success	Taunt
Feature	Rouse
Achieve	Genre
State	Corrupt
Contrast	Par
Passage	Creed
Wealth	Browse
Vary	Quip
Refer	Pun
Crew	Flaw

Appendix E

Target/prime stimuli used in Chapter 6

Target and motor prime/semantic prime/neutral prime

Broom and spade/witch/truck

Bulb and pear/switch//tail

Pen and lipstick/classroom/fence

Stone and button/beach/van

Cigarette and crayon/cough/mountain

Egg and chestnut/hen/path

Dice and grapes/cards/roof

Eraser and badge/error/shower

Bowl and nest/soup/lake

Notebook and wallet/essay/tower

Chalk and battery/blackboard/couch

Tile and plate/bathroom/cliff

Wire and thread/socket/shore

Disc and lid/computer/shrub

Pearl and bean/ocean/hut

Pill and pea/chemist/wardrobe

Twig and peg/branch/hill

Melon and ball/juice/pond

Cable and twine/shock/grass

Sweet and pebble/shop/bath

Screw and thimble/wall/tap

Plunger and stick/toilet/bus

Acorn and strawberry/squirrel/tent

Key and paperclip/cabinet/jungle

Cloth and sock/sink/porch

Placemat and booklet/table/vent

Candle and carrot/wax/planet

Pencil and toothbrush/homework/mast

Chain and ribbon/jeweller/bench

Toothpick and needle/gums/shed