Are Action Concept Deficits Embodied in a Topographic Manner in Adults with Cerebral Palsy?

by

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Abstract

In Cerebral Palsy (CP) children commonly experience semantic deficits. The cause of semantic deficits, and persistence into adulthood, are unknown. The social network hypothesis states decreased frequency of language use in CP individuals leads to impoverished lexico-semantic representations. The embodied cognition hypothesis emphasizes the role of the motor system in processing action concepts. In this study, participants first completed a sentence-reading task while their event related potentials (ERPs) to semantically incongruent sentences were collected. No evidence was found that CP individuals process domain-general semantic incongruence differently to neurotypicals. Participants then made action decisions on lower-limb (*kick*), and psychological verbs (*believe*) in an identity-priming paradigm. The ERP component of interest was the N400. There was no evidence to suggest CP individuals have action verb impairments. If the motor system contributes but is not necessary for action semantics, then participants may present no deficits when compared to neurotypicals as shown here.

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Chapter 1: Introduction

Cerebral Palsy (CP) is a group of permanent disorders of the development of movement and posture causing physical activity limitations (Bax et al., 2005; Minear, 1956; Palisano et al., 1997). These limitations include trouble executing gross motor movements. Individuals with CP often experience difficulty walking and maintaining balance in confined spaces with many people, or on uneven surfaces. These disorders are attributed to various disturbances that occur in the developing fetal or infant brain. Most commonly, CP is caused by pre-natal or neo-natal hypoxia, twin reversed arterial sequence (TRAP sequence), maternal infections during pregnancy (e.g., meningitis), or seizures occurring in the infant before 24 months (Farmer & Sabbagh, 2007; Hoon et al., 2009; Minear, 1956; Novak et al., 2017; Tan & Sepulveda, 2003).

Although the motor deficits are the key diagnostic features of CP, individuals with this condition often experience disturbances of sensation (Cooper, 1992; Hoon et al., 2009), cognition (Fennell & Dikel, 2001; Pueyo, Junqué, Vendrell, Narberhaus, & Segarra, 2008), language and speech (Pennington, 2008; Vos et al., 2014) and/or perception (Bax et al., 2005; Ghasia, Brunstrom, Gordon, & Tychsen, 2008; Wingert, Burton, Sinclair, Brunstrom, & Damiano, 2008). Among compromised non-motor abilities in individuals with CP, language and speech deficits have been examined most extensively. However, the overwhelming majority of this research has been done with children (Bishop, Byers Brown, & Robson, 1990; Chorna, Hamm, Cummings, Fetters, & Maitre, 2017; Pennington, 2008; Pennington, Smallman, & Farrier, 2006; Pinto & Gardner, 2014; White, Craft, Hale, & Park, 1994). In the following work, I examined language processing in adults with CP. Specifically, I explored in Experiment 1 whether there is a general semantic deficit in CP individuals. In Experiment 2, I explored whether the potential deficit was restricted to a particular semantic domain.

1.1. Motor impairments in individuals with CP

Diagnosis of CP is a complex and lengthy process as it involves ruling out all other possible neurologic and motor impairments including muscular dystrophy, spina bifida, and generalized weakness disorders which fit the symptomology (Bax et al., 2005; Minear, 1956; Novak et al., 2017; Palisano et al., 1997; Palisano, Avery, Gorter, Galuppi, & McCoy, 2018). If a child does not meet the criteria for the above disorders, CP is their diagnostic catchall. A CP diagnosis now involves three elements: type, topography, and gross motor severity.

1.1.1. The elements of a CP diagnosis

Under the current definition of CP, there are four types of CP that are distinguished based on both symptomatology and affected brain areas. Generally symptomatology is identified first and an MRI follows to confirm the type (Novak et al., 2017). The first and the most common type of CP is spastic CP. This type of CP stems from damage to the motor cortex, which is implicated in acting on the desire to move. Symptoms specific to spastic CP include increased muscle tone in limbs, and as a result of the increased tone, muscles are shortened or atrophied (Gilette Childen's Specialty Healthcare, 2009; Minear, 1956; Pennington, 2008).

The second type of CP - athetoid CP - is caused by damage to the basal ganglia, which is implicated in the selection of appropriate movement sequences. As a result, athetoid CP is characterized by an increase in involuntary movement and affects the coordination of movements, such as walking, that involve many muscle groups (Gilette Childen's Specialty Healthcare, 2009; Minear, 1956). Individuals with athetoid CP also experience the most communication disorders. This is likely because the involuntary movements which are the hallmark of this topography cause difficulty articulating speech sounds, although cognitive and communication deficits do also largely depend on an individual's condition severity (Hidecker et al., 2012; Pennington, 2008).

Finally, ataxic CP stems from damage to the cerebellum, which compares intended movements with the actual movement performed. Damage to this region causes tremors and poor coordination most often presented as unsteady walking (Minear, 1956). In rare cases two symptomologies may be present in an individual, this is known as mixed CP (Bax et al., 2005; Minear, 1956).

CP is also characterized from the point of topography of movement constraints (i.e., which limbs are affected by the condition; Minear, 1956; Novak et al., 2017). A hemiplegic individual with CP has one half of their body affected by CP symptoms (either left or right), while the opposing side remains completely unaffected (Bax et al., 2005; Minear, 1956). A paraplegic individual has both of their lower limbs affected by CP symptoms. A diplegic individual has primarily their lower limbs affected, although upper limb functioning is also slightly compromised in these individuals (Bax et al., 2005; Minear, 1956). Finally, a quadriplegic individual has all their limbs affected and to a more severe extent than the other topographies. Quadriplegic individuals cannot walk independently (Bax et al., 2005; Gilette Childen's Specialty Healthcare, 2009; Minear, 1956).

Finally, CP varies in severity of motor dysfunction. The current gold standard for classification is the Gross Motor Function Classification Scale (GMFCS) shown in *Figure 1*. The GMFCS is a valid and reliable way to assess a child's ability to initiate and perform self-directed gross motor movements on a scale of one to five (Palisano et al., 1997, 2000; Palisano, Rosenbaum, Bartlett, & Livingston, 2008). After the age of 12 the GMFCS score remains stable in 89% of children throughout their lifetime (McCormick et al., 2007). The GMFCS provides parents and clinicians with information regarding corrected developmental milestones.

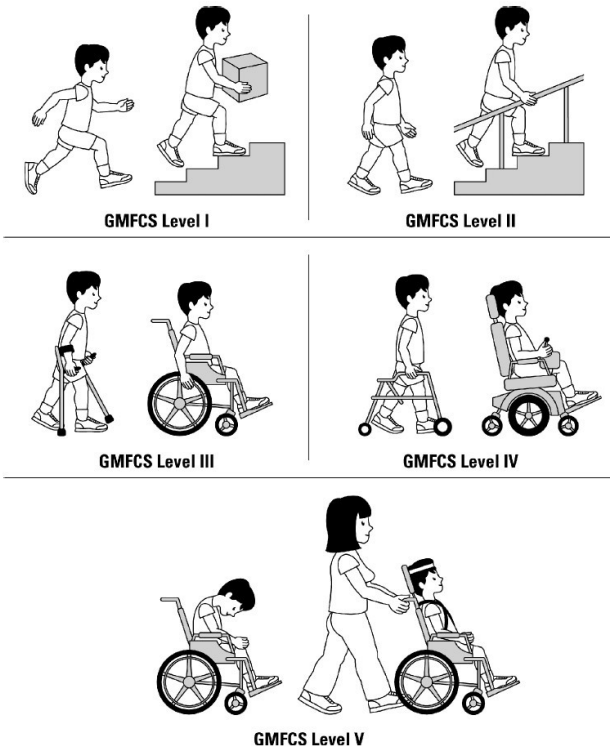

*Figure 1***.** Diagnostic criteria of each level of the Gross Motor Function Classification Scale (GMFCS). This classification depicts how an individual with differing degrees of gross motor impairement would walk on a daily basis. Adapted from Palisano et al. (1997, 2000, 2008).

Putting all the elements together, a CP diagnosis may read: spastic diplegia with a GMFCS score of level two. This means that the child has a lesion or abnormal development in their motor cortex, and their lower limbs and to a lesser extent their upper limbs are affected by their disability. Moreover, the child will have trouble initiating gross motor movements in busy or uneven environments and may require non-motorized walking aids.

CP has traditionally been diagnosed in infants between 12 and 24 months of age. However, recent studies have suggested that with the use of MRI to locate lesions at time of diagnosis, up to 50% of CP diagnoses could be made as early as five months corrected age, which is a premature baby's chronological age minus the number of weeks or months that he was born early (Novak et al., 2017).

1.1.2. The benefits of early intervention and rehabilitation

Once a diagnosis has been confirmed and a GMFCS score assigned, the majority of individuals are entered into a rehabilitative program. Currently there is no cure for CP but motor and speech functioning may be improved (Blauw-Hospers & Hadders-Algra, 2005; Cameron, Maehle, & Reid, 2005; Novak et al., 2017; Wynter et al., 2015). However, evidence suggests that infants who do not engage their motor cortices risk losing valuable neuronal connections to their affected limbs and their motor cortex as a dedicated functional unit, similar to when blind individuals have their visual cortex repurposed for auditory functioning (Bedny, Richardson, & Saxe, 2015; Eyre, 2007). Therefore, early rehabilitative measures, such as therapy, are really the key to functionality. Early intervention across all CP subtypes maximizes an individual's physical functionality, while minimizing harmful muscle atrophy and bone loss (Eyre, 2007). For both physical mobility and speech outcomes such interventions include both medications to reduce spasticity, and recurrent therapy (Cameron et al., 2005; Eliasson & Holmefur, 2015; Fehlings et al., 2012; Kim et al., 2011).

One way to lessen symptoms is by administering pharmacological agents. Children and adults are commonly administered anti-spasticity agents such as Botulism Toxin A or Baclofen. These drugs promote GABA production, an inhibitory neurotransmitter that as a consequence reduces spasticity and involuntary movements throughout the body by impeding excitatory neurotransmitters. Children and adults who received continuous intrathecal Baclofen infusion dosages from 27 to 800 micrograms per day had improved range of motion outcomes (Albright, 1996). Continuous intrathecal Baclofen infusion reduced spasticity in the upper and lower extremities (Albright, 1996). The anti-spasticity effects of these drugs have been consistently replicated (Fehlings et al., 2012; Kim et al., 2011; Ramstad, Jahnsen, Lofterod, & Skjeldal, 2010). Baclofen's muscle relaxant effects even aid speech intelligibility

by reducing dysarthria (Carvalho Lima, Collange Grecco, Marques, Fregni, & Brandão de Ávila, 2016; Leary et al., 2006; Mason, Gilpin, McGowan, & Rossiter, 1998).

The outcomes of recurrent physical therapy are also overwhelmingly positive across all subtypes of CP (Cameron et al., 2005; Ma et al., 2015). Spastic hemiplegics enrolled in constraint induced motor therapy (CIMT) as neonates have better hand control in short and long-term assessments over controls (Eliasson & Holmefur, 2015). Spastic and athetoid individuals going for hip x-rays every six to twelve months starting at birth also undergo fewer revision surgeries and suffer less pain than if they were to wait for their hips to displace before seeking monitoring (Elkamil et al., 2011; Wynter et al., 2015).

Motor and speech interventions can be extremely successful in decreasing CP symptoms. The only caveat is that treatments must be started as soon as possible following diagnosis to ensure no motor neuron connections are lost. Despite the fact that CP has no cure, beyond the age of 12, 89% of children remain at a stable gross motor function level (McCormick et al., 2007), a testament to the benefits of early interventions.

1.2. Cognitive deficits in individuals with CP

While fine and gross motor skills are prominently the motor skills affected in CP, recent evidence has also arisen to show that the cognitive processes surrounding motor skills might also be impaired (Van Elk et al., 2010). In an EEG study, the neural and temporal dynamics of action planning in participants with right-sided hemiplegia were investigated using an anticipatory planning task. Participants were required to grasp and rotate a hexagonal knob over different angles (60°, 120° or 180°). Not only were CP participants slower in deciding how to grasp their object and do so correctly but they also showed a strong reduction in the amplitude of the P2 component with a strong correlation observed between the P2 amplitude and grasping and rotation times. As the P2 component was localized to sources in the dorsal

posterior cingulate cortex (dPCC), an area known to be involved in orienting body parts in one's environment, these findings suggest that anticipatory planning deficits in CP arise mainly due to an impaired process of action selection (Van Elk et al., 2010). Cognitive action impairments are also known to extend to the realm of linguistics where children have been shown to have smaller vocabularies and slower reading times for words describing actions than typically developing children (Lampe, Turova, Blumenstein, & Alves-Pinto, 2014; Levi, Colonnello, Giacchè, Piredda, & Sogos, 2014; Pueyo et al., 2008).

1.3. Speech and language deficits in individuals with CP

Out of all non-motor deficits, difficulties in speech and language use are the most common non-diagnostic features of CP. Pennington (2008) estimated that up to 45% of children with CP experience language and communication deficits. Moreover, only 3.6% of CP adults show right ear superiority for language, which is a hallmark of language processing in individuals with typically developing linguistic abilities. Right ear superiority occurs because the brain controls the contralateral limbs, and language is attributed to left temporal lobe functions (Hothersall, 1995). The idea is that atypical cerebral lateralization adds to or interacts with the genetic risk factors for language impairment (Bishop, 2013).

In CP, there are two linguistic domains in which deficits are commonly present: phonology (Bunton & Weismer, 2001; Kim, Hasegawa-Johnson, & Perlman, 2011; Lee & Hustad, 2013; Liu, Tsao, & Kuhl, 2005; Stipancic, Tjaden, & Wilding, 2016) and lexico-semantic knowledge (Byrne, Dywan, & Connolly, 1995; Lampe et al., 2014). Speech and language deficits appear to be more severe in individuals with non-spastic types of CP (Vos et al., 2014). In individuals with unilateral spastic CP, expressive language and speech abilities are often not compromised (Roser Pueyo, Junqué, Vendrell, Narberhaus, & Segarra, 2009; Vos et al., 2014).

1.3.1. Phonological deficits in individuals with CP

Due to deficient development of fine-motor movements, children with CP have difficulty organizing speech sounds, causing issues of speech intelligibility, slow speech rate, dysarthric speech, and/or stuttering (Pennington, 2008; Weber-Fox & Cuadrado, 2003; White et al., 1994). CP children also have delayed literacy skills because of these deficits (Kiessling, Denckla, & Carlton, 1983; Levi et al., 2014; Pennington, 2008; Sandberg & Hjelmquist, 1996).

Experimental evidence for phonological deficits comes from a variety of paradigms including blind transcription and electromyography (EMG) studies (Kim et al., 2011; Neilson & Dwyer, 1984; Quinn & Andrews, 1977). For example, Kim et al. (2011) recorded speech of adults with and without CP and then presented it to individuals with neurotypical (NT) linguistic abilities. NT participants transcribed spoken words produced by individuals with CP. In addition, transcribers were asked to indicate certainty of their word choice from zero-two. Individuals with CP were classified into four groups from these transcriptions, depending on intelligibility of their speech. Next, the researchers conducted a phonological analysis of speech of CP participants in each intelligibility group. Highly intelligible NT and CP speakers made four levels of vowel height distinction as usual and had the largest vowel space overall. Mid to low intelligibility speakers, all CP speakers, did not maintain a mid-high lax or high lax-tense distinction, mixing vowel phonemes and as such had reduced mean space between their vowels overall. Further, very low intelligibility CP speakers showed a further reduction in height distinction by grouping /a/, /e/ and /ʊ/ phonemes (Kim et al., 2011). Overall, unintelligible speakers had more vowel-phoneme overlap, less stability in vowel height, reduced articulatory vowel space, and reduced mean distance between vowels than highly intelligible CP and NT speakers. These findings have been replicated multiple times in English (Bunton & Weismer, 2001; Kim et al., 2011; Lee & Hustad, 2013; Liu et al., 2005; Stipancic et al., 2016).

While non-essential muscle activity, known as ticks or spasms are common in CP, they do not significantly affect the production of difficult patterns of sounds as shown by EMG readings taken on lip tongue and jaw muscles during repetitions of words that involve large and varied articulatory movements (Neilson & Dwyer, 1984). Ten subjects, five with and five without CP, all read the sentence "Do all the old rogues abjure weird ladies" 50 times. Syllables in the test sentence were produced more slowly and at a more variable rate in the CP individuals. However when the EMG activity associated with each syllable was partitioned into reproducible and variable components the ratio of reproducible signal and variable components of the EMG waves were similar between groups (Neilson & Dwyer, 1984). Involuntary movements occurred mostly between syllables and accounted for time variations in syllable production. This shows that involuntary jaw movements do not directly affect speech sound production.

While evidence for phonological deficits in speech production in CP has been demonstrated consistently (Bunton & Weismer, 2001; Kim et al., 2011; Lee & Hustad, 2013; Liu et al., 2005; Stipancic et al., 2016), evidence for a phonological deficit in speech recognition is lacking (Quinn & Andrews, 1977; Vos et al., 2014). Quinn and Andrews (1977) reported that CP individuals could easily discriminate words from non-words despite production deficits. In a dichotic listening task, participants heard six pairs of consonant-vowel-consonant (CVC) words presented over three seconds, with headphone reversal between trials, for 12 trials. Some items were genuine words; other items were impossible sound combinations in English. Participants indicated what words they had heard. Performance of individuals with CP in this task was comparable to the NT group (Quinn & Andrews, 1977), indicating preserved phonologic recognition in CP.

To conclude, it is important to note that the literature surrounding CP linguistic deficits does not make a clear distinction between phonetic (deals with the organs of sound

production), and phonological deficits (deals with the sounds and their changes). In the vowel contrast studies, though they discuss "phonological vowel distinctions", the root of their findings seems to stem from an articulatory (phonetic) deficit. Follow-up studies could try to sort out whether the speakers have truly merged their vowels phonologically, or whether the merger is exclusively due to production (articulation) and be sure to label the deficits distinctively.

1.3.2. Lexico-semantic processing deficits in individuals with CP

Compared to research on phonological deficits in CP, lexico-semantic processing remains largely uninvestigated in adults with CP (Vos et al., 2014). In spite of the small pool of adult-centered research, the results do support the claim that as in children, impoverished semantic and lexical representations do occur predictably.

The semantic deficit in question has been studied from both a behavioural and neurocognitive standpoint. Starting with the behavioural evidence, Lampe et al. (2014) conducted a reading study involving CP adults and NTs. Participants read short stories out loud from a screen while four cameras tracked participant's eye-movement. Higher variability in fixation time (processing speed) and regressions (re-reading) in the CP group indicated they had more trouble performing the task. Reading rate was also significantly slower in the CP group. For individuals with dysarthria, reading rate was 49 words per minute compared to 134 words per minute in healthy NTs. Saccades were more frequent and their duration longer for the CP group with dysarthria meaning they took longer to search for new words/had to keep bringing information into memory with short frequent regressions. With this in mind then, the varied saccade length and frequent regressions show a possible difficulty searching impoverished lexical and semantic representations instead of simply not processing meaning, as good comprehension scores were reported in some cases. However these results are less clear as it may also be that that CP individuals made more regressions as they read because of

limited working memory capacity as has been previously reported (White et al., 1994). They might have also been reading slower because of difficulty mapping letters onto phonemes rather than a deficit in their lexicon.

To further probe the lexical access abilities of CP adults another eye tracking paradigm was administered by Fishman (2018). This study examined the time course of phonological and semantic activation during spoken word recognition in adolescents and adults with CP and compared their performance with results of NT adults. In particular, the goal was to determine whether individuals without spoken language activate phonological and semantic competitors. With limited production abilities (Kim et al., 2011; Lampe et al., 2014; White et al., 1994) and evidence of limited phonological knowledge (Bunton & Weismer, 2001; Kim et al., 2011; Lee & Hustad, 2013; Sandberg & Hjelmquist, 1996), as well as semantic knowledge (which is first filtered through phonology), individuals with CP were not expected to activate the competitor's lexical representation (Fishman, 2018; Huang & Snedeker, 2011). In contrast, this activation was expected in NT adults. In each trial, participants saw five images, while listening to a spoken word as their eye movements were monitored. Each trial consisted of an auditory target word (e.g. *tire*), and four pictures including a picture corresponding to the target word, a phonological competitor (e.g. *tie*), or a semantic competitor (*tie/shirt)* and two images that were phonologically and semantically unrelated to the target. An additional competitor semantically related to a word that had the same phonological onset included a picture that was semantically related to an absent phonological competitor of the target (e.g., the target is *tire* and the competitor is a picture of a *shirt* related to absent *tie*). Fixation analysis indicated phonological competition was very strong while semantic competition was much weaker for the CP group (Fishman, 2018). In contrast, the NT adults rapidly fixated on the target picture, did not demonstrate significant fixations to phonological competitors and demonstrated marginally significant proportion of fixations to semantic relatives (Fishman, 2018).

Examining individual performance, those who spent more time fixating on competitors in the phonological condition also fixated more on competitors and distractors in the semantic condition. Those who quickly eliminated competitors in the phonological condition also did so in the semantic condition. This suggests that in fact phonologic and semantic deficits in CP may be intertwined as put forward by TRACE theory (Huang & Snedeker, 2011), the ramifications of which will be further discussed in Section 1.4.

The effects of intelligence on semantic deficits have also been investigated as a way to further understand if and why semantic deficits occur predictably in CP. Pirila et al. (2017) hypothesized that children with an intelligence level above 70 have primarily motor speech problems, whereas children with an intelligence level below 70 have additional verbal expressive and comprehensive problems. 36 children and young adults completed a battery of comprehension and motor speech assessments (Pirila et al., 2007). The raw scores of the comprehension and the expressive tests were transformed into language age equivalents. The more severe the CP, the more frequent were the problems in expression and comprehension. More specifically, one-half of the participants with an intelligence level at or close to normal, showed impairments primarily in the motor speech domain, whereas participants with additional cognitive difficulties (intelligence level below 70) showed impairments both in language and motor speech skills (Pirila et al., 2007). These results indicate that disability severity and intelligence level directly affect semantic deficits in CP.

Because disability severity correlates with semantic deficits, being able to reliably assess comprehension across the CP population is important. Geytenbeek et al. (2014) developed an instrument to provide information on the comprehension performance of CP children, relative to their NT peers, using test items and response activities that were specifically designed for children with severe physical disabilities. The test had participants identify nouns and verbs by pointing at the correct response to increasingly difficult probe

sentences (e.g., *where is the shoe*?). The test was administered to 831 children and young adults with typical development and 90 children with CP and complex communication needs. The study provided evidence of good reliability and good validity when using this computer-based tool in the CP population to asses language comprehension (Geytenbeek, Mokkink, Knol, Vermeulen, & Oostrom, 2014). As expected, in participants with CP, Computer-Based Instrument for Low Motor Language Testing (C-BiLLT) scores varied considerably and (overall) were significantly lower than in NTs. Moreover, high *SD*s were found for in participants with CP in all age groups, indicating that C-BiLLT scores showed a large range of values and higher variability in the CP group (Geytenbeek et al., 2014).

Evidence for a universally present semantic deficit in individuals with CP seems unlikely, as we have already seen it can be mediated by intelligence. Certain brain pathology may also be necessary to have such a deficit. Kiessling et al. (1983) found that right-hemiplegic children performed significantly poorer than left-hemiplegic children and NTs on measures of semantic processing, despite similar verbal IQs. The “Binet Sentences” adapted from the Binet test for intelligence were used as a measure of repetition ability for semantically coherent materials, with an age-equivalent score developed for each child. Right hemiplegics performed significantly worse on the semantic task than left hemiplegics. Moreover, impairment severity trended towards being correlated with measures of disability severity, although this did not quite meet statistical significance. Thus it seems the case that semantic deficits are not universally present in all CP participants but only in those who have their brain damage localized to the left hemisphere, and that the deficit worsens with disability severity.

From the neuro-cognitive standpoint comes a study the most similar to the work presented in this thesis. Bryne et al. (1995) reported that a semantic deficit might occur in CP adults. They ran an ERP study with no behavioural component which used the Peabody

Picture Vocabulary Test-Revised (PPVT-R) as stimuli, with three levels of difficulty (*Preschool, Child, Adult*), to test semantic knowledge in a single adult with CP. Individual pictures were presented in succession, and correctly (congruent) or incorrectly (incongruent) named with a verbal response as opposed to a key press. As predicted, the N400 ERP component, which reflects the normal brain response to words and other meaningful (or potentially meaningful) stimuli had a higher amplitude for the incongruent picture-word pairs at the *Preschool* and *Child* levels in the CP individual and NTs. At the *Adult* level, the ERP pattern was reversed (higher amplitude in congruent condition) for the CP adult but not all NTs (Byrne et al., 1995). The reversal pattern, which occurred only in the *Adult* condition for the CP participant, indicates that picture-word pairs within the range of acquired receptive vocabulary were identified as correct or incorrect, but picture-word pairs above an individual's knowledge level could not be differentiated as clearly. This suggests impaired lexico-semantic representations may be present in the CP individual as they were an adult and should have had a receptive vocabulary similar in level to the NTs (Byrne et al., 1995).

This paradigm was used again later with a larger group of 56 five- to twelve-year olds. The results indicated that picture-word pairs within the range of acquired receptive vocabulary were easily identified as correct or incorrect with a larger wave deflection in the incongruent condition in all age groups (Byrne et al., 1999). The newer result makes the findings from Byrne et al. (1995) stand out as atypical.

In sum, lexico-sematic representations can be impoverished in CP individuals (Fishman, 2018; Geytenbeek et al., 2014; Lampe et al., 2014), but having a lower intelligence and/or brain pathology localized to the left hemisphere (Kiessling et al., 1983; Pirila et al., 2007), makes the incidence rate of such a deficit more likely. With the exception of correlational evidence (Kiessling et al., 1983; Pirila et al., 2007), it remains unclear whether the semantic deficit present truly maps to disability severity. Moreover, no study has

determined if there is a relationship between the topography of one's CP and their semantic deficit. It may be the case that individuals with diplegia, for example, show a more profound deficit in processing action words relating to lower limb usage.

1.4. Potential mechanisms of lexico-semantic deficits in CP

Whereas phonological deficits are likely to be caused by incomplete mastery of fine motor skills and articulatory mechanisms (Kim et al., 2011; Neilson & Dwyer, 1984; Pennington, 2008; Sandberg & Hjelmquist, 1996; Weber-Fox & Cuadrado, 2003; White et al., 1994), causes of lexico-semantic deficits are less clear.

One view in the literature is that lexico-semantic deficits are a consequence of phonological deficits (Fishman, 2018; Huang & Snedeker, 2011). Because phonological and semantic processes are intertwined, any weakness in activation at one level can impact another level. Word recognition can thus be seen as a flow of information with simultaneous phonological and semantic information activation which could explain the reciprocal influence between impoverished semantic and phonological word representations in individuals with CP. In sum, less efficient phonological processing interferes with semantic activation, supporting the view that phonological information influences semantic representations (Fishman, 2018).

However, I need to be able to explain the phonological deficits independently from the lexical because while they do not occur independently in individuals with CP, the deficits have occurred independently elsewhere. For example, a deficit in phonological abilities without a deficit in lexical processing has been reported in individuals who stutter (Blomgren, Nagarajan, Lee, Li, & Alvord, 2003; Weber-Fox & Cuadrado, 2003).

Here I will consider two alternative causes/mechanisms for the lexico-semantic deficits in individuals with CP, mechanisms that explain the semantic deficits independently from the phonological ones: a social network type mechanism and an embodied cognition type mechanism. According to the social network view, because language learning relies on

statistical extraction, decreased frequency of language use in CP individuals may lead to underdeveloped lexico-semantic representations (Lev-Ari, 2016, 2017; Lev-Ari & Shao, 2017). Alternatively, an embodied cognition view holds that because lexico-semantic representations involve partial reinstatement of brain activity during experiences and actions the words are typically used to speak about (Hickok, 2010; Kiefer & Pulvermüller, 2012; Prinz, 1997; Taylor, Lev-Ari, & Zwaan, 2008), it is possible that by not being able to perform certain actions CP individuals have corresponding lexico-semantic deficits.

1.4.1. Semantic deficits in CP are caused by restricted social interactions

Lexico-semantic impairment might be an unfortunate side effect of limited mobility. Over the last few decades, research has increasingly demonstrated that language learning relies on the statistical extraction of patterns from the linguistic environment (Lev-Ari, 2016, 2017; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997; Theofanopoulou, Boeckx, & Jarvis, 2017). Infants as young as eight months can discriminate words from non-words, with longer listening times for non-words meaning they can extract linguistic phoneme patterns effectively (Saffran, Aslin, & Newport, 1996). These results have been replicated by having children and adults learn word segmentation rules of artificial languages with overwhelming success (Berko, 1958; Saffran et al., 1997). This statistical learning approach to language acquisition is the basis of the social network hypothesis (SNH). It may be the case that, exposure to a wider distribution of language uses and users (i.e., large social networks) assists an individual in picking up linguistic statistics correctly, which, in its turn, helps them to interpret expressions quickly and correctly. If individuals are limited in the number and types of linguistic interactions they engage in (e.g., because of their limited mobility), they are extracting statistical patterns from an impoverished linguistic environment (i.e., small social network). As a result, lexico-semantic representations that these individuals acquire differ from the ones that are represented in language being used by the majority of speakers. According to Lev-Ari (2017), the SNH

predicts that individuals with smaller social networks also have more malleable representations and are more likely to adjust their general representation of phonological categories following exposure to non-normative input. Lev-Ari proposed that this greater malleability of representations is due to the fact that when one has only been exposed to few sources, any new source is more informative, and therefore its input is assigned more weight.

Lev-Ari (2016, 2017) formulated the key ideas of the SNH and tested them in NTs. Lev-Ari (2016) tested whether social network size influences global comprehension by having people with varying numbers of weekly interactions read restaurant reviews and estimate the star rating associated with each review. She found that the more interlocutors participants interacted with in a typical week, the more accurate they were in interpreting tonality of written reviews and their corresponding numerical scores. Specifically, interacting with about ten more people per week improved accuracy by about 2%. This study showed that increasing social network size increased comprehension of evaluative descriptions. As these results may have been influenced by word exposure rates, a follow up study was conducted.

In the follow up study, participants were exposed to novel words, which appeared in contexts that facilitated their interpretation. The goal of the study was to examine whether learning from social networks of different sizes influenced comprehension of these words. The results replicated the results of Lev Ari (2016), showing that participants who had eight speakers giving them feedback after they used a novel word in a sentence were more accurate in defining novel words than participants who learned and received feedback from two speakers, when exposure was held constant and network size was manipulated (Lev-Ari, 2016). Having larger social networks does influence linguistic skills to some degree, specifically semantic comprehension ability (Lev-Ari & Shao, 2017).

Individuals with disabilities may have fewer opportunities to communicate with others than NTs because their movement is limited and they rely on others for transportation

(Cadman, Boyle, Szatmari, & Offord, 1987; Morgan, Patrick, & Charlton, 1984; Reddihough et al., 2013). Presence of speech pathologies mixed with a physical disability might also make them less willing or more anxious to interact with others actively, leading to fewer friendships overall (Adriaensens, Van Waes, & Struyf, 2017; Alm, 2014). So, individuals with CP have a decreased frequency of language use and socialization. The SNH would predict that the limited social interaction of individuals with CP leads to their impoverished lexico-semantic representations.

A study examining deficits in Supranuclear Palsy (SP) supports this line of reasoning. SP affects balance, eye movements, and walking due to midbrain and frontal lobe deterioration. SP leads to severe motor impairments, widely varying amongst individuals. Daniele et al. (2013) had SP adults complete oral and written naming tasks, where they were to name pictures depicting objects/actions. Here, actions were harder to name than objects, both verbally and when written. This is because SP individuals had widespread impoverished lexico-semantic representations as evidenced by a dysfunction of neural systems in posterior frontal cortical areas mainly involving the inferior frontal gyrus. SP individuals showed overall deficits in verb naming not limited to verbs pertaining to their affected limbs, suggesting a SNH-type cause. Similar results emerged in the picture mapping comprehension task where again participants had a harder time selecting the appropriate action to match a target word, out of three possible photos compared to when selecting objects. These results reinforce a social network type cause as lexico-semantic knowledge was again globally compromised in individuals and not restricted to any specific semantic domain.

If this hypothesis is indeed correct, in the present study I expect that lexico-semantic knowledge be globally compromised in individuals with CP (i.e., it is not restricted to any specific semantic domain).

1.4.2. Semantic deficits in CP are caused by impoverished neural representations of action knowledge

Some researchers argue that concepts are mental representations which are built based on sensory and motor experiences that our bodies have with corresponding objects in the environment (Kiefer & Pulvermüller, 2012; Patterson, Nestor, & Rogers, 2007). This approach to conceptual representations is known in the field of semantics as the embodied cognition hypothesis (ECH) (Levi et al., 2014; Mahon & Caramazza, 2008; Miller, Brookie, Wales, Wallace, & Kaup, 2018; Ong, Lohse, Chua, Sinnett, & Hodges, 2014; Taylor, Lev-Ari, & Zwaan, 2008; Willems et al., 2017). The ECH is a spectrum. A strong or radical view would posit that mental representations are empty and that cognition does not happen merely in the head but extends to the entire body (Goldinger, Papesh, Barnhart, Hansen, & Hout, 2016). Concepts are embodied in the sense that interactions with the environment lead to the formation of memory traces in modality specific brain areas, which typically process the corresponding sensory and motor information. Access to a concept involves partial reinstatement of brain activity during experiences and actions the words are typically used to speak about (Kiefer & Pulvermüller, 2012). For example, the process of retrieving the concept HAMMER would itself be constituted by the retrieval of (sensory and motor) information about how to use hammers (i.e., swinging the arm, grasping the hammer etc.). For language comprehension, this means that in processing action verbs the motor cortex (M1) must be activated at all times producing a mental movie of sorts as we process action language. However, the majority of language is not directly tied to action and if vanishingly few sentences are suitable candidates for motor simulation then positing simulation as a core principle is theoretically empty. Although handing something to someone could activate a motor simulation, how would the rest of the sentence become part of that simulation, in advance of sentence understanding? There are well-known theories in word perception wherein semantic features can generate top-

down feedback to facilitate perception, typically for words that are disadvantaged (low-frequency, inconsistent words (Harm & Seidenberg, 2004; Strain, Patterson, & Seidenberg, 1995). Such a system could be conceived for motoric features, which are conceptually akin to concreteness, but their potential role is logically limited to a small set of sentences (Goldinger et al., 2016). This leads to the growing popularity of weak over strong views of cognition as a weak view still allows a hybrid view where we create representations of abstract concepts and a special embodied process to create representations for concrete actions and objects (Mahon & Caramazza, 2008). Most researchers now take a milder and weaker stance where concepts are essentially grounded in perception and action (Goldinger et al., 2016; Kiefer & Pulvermüller, 2012; Mahon & Caramazza, 2008). The weaker view posits that in terms of language comprehension, M1 regions are an accessory to linguistic processing rather than a necessity. Currently, the majority of research, and that research presented here was originally posited to be in line with the strong view of embodied cognition but can be equally consistent with the weaker view without being overly restrictive.

Prior research has provided convincing evidence demonstrating that comprehenders understand speech by constructing a perceptual simulation of the events being described, and as such, motion perception can affect language processing (Glenberg & Kaschak, 2002; Kaschak et al., 2005; Taylor et al., 2008; Zwaan, Stanfield, & Yaxley, 2002). One study found that participants read sentences and responded with a directional movement faster when sentences implied motion that was congruent with the direction of an action they were performing. Such that when a sentence implied action in one direction e.g., *Close the drawer*, which implies action away from the body, the participants had difficulty making a sensibility judgment requiring a response in the opposite direction (or towards the body) (Glenberg & Kaschak, 2002). This congruency effect has been consistently found and supports the embodied cognition view (Glenberg & Kaschak, 2002; Taylor et al., 2008; Zwaan et al., 2002).

Despite the replicability of the congruency effect not all studies are in agreement. In Kaschak et al. (2005), participants heard sentences describing motion in a certain direction while watching circles spin on a screen in the same or opposite direction to the described motion. It was shown that grammaticality and sensibility judgments were made faster to sentences presented concurrently with a visual stimulus depicting motion in the opposite direction as the action described in the sentence (Kaschak et al., 2005). The data suggest that there is considerable specificity in the simulations constructed during language comprehension. Perceiving motion did not simply interfere with the comprehension of language about motion; rather, perceiving motion in a particular direction selectively impaired processing of sentences that describe motion in that same direction. Action kinematics and perceived ability also affect reaction times of motion and action verbs processing, indicating that indeed the simulation formed during verb comprehension is very detailed and reflects the real interrelations between our body and the seen object (Ambrosini, Scorolli, Borghi, & Costantini, 2012; Beauprez & Bidet-Ildei, 2018; Costantini, Ambrosini, Sinigaglia, & Gallese, 2011; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010). Taken together, these studies are in line with the claim that sensory semantic and motor systems rely on partially overlapping neural substrates (Prinz, 1997). These common substrates even emerge as early as infancy, highlighted by the fact that language comprehension and production scores correlate to gross motor scores in children as young as 21 months of age (Alcock & Krawczyk, 2010).

1.4.2.1. Evidence for the embodied cognition view from studies of individuals with typical physical functioning

There is some neuropsychological evidence that sensory and conceptual areas are functionally and neuro-anatomically linked for visual, auditory and odour related words (González et al., 2006; Kiefer & Pulvermüller, 2012). For example reading odour words such as cinnamon activates the primary olfactory cortex compared to odour neutral words (González

et al., 2006). Embodied concepts are a very extensively studied topic not only in the field of linguistics but also in many areas of neuroscience and cognitive science.

The relation between motor system and action conceptual knowledge has also been extensively investigated (Buccino et al., 2005; Hauk, Johnsrude, & Pulvermüller, 2004; Hauk & Pulvermüller, 2004; Hickok, 2010; Kiefer & Pulvermüller, 2012; Mahon & Caramazza, 2008; Repetto, Colombo, Cipresso, & Riva, 2013). All branches of the ECH see cognition as a process of perceptual simulation and would predict that processing of action related words (e.g., *kick* or *kiss*) entails activation of effector-specific regions of premotor cortex. Indeed, such evidence has been provided (Hauk et al., 2004; Hauk & Pulvermüller, 2004; Hickok, 2010). Processing of the word *kick* is associated with activity in the motor areas corresponding to leg movements, while processing of the word *kiss*, leads to increased activity in motor areas corresponding to facial movements (Hauk et al., 2004; Hauk & Pulvermüller, 2004; Hickok, 2010). Similar results demonstrating increased activation in motor areas when processing action words over abstract words have been found in transcranial magnetic stimulation studies suggesting a facilitatory effect of the primary motor cortex on semantic processing, confirmed by the fact that the temporary disruption of that area resulted in a delay of the reaction times with action verbs only (Buccino et al., 2005; Hickok, 2010; Repetto et al., 2013). This motor specific activation pattern when processing action words mirrors the somatotopy of the motor cortex suggesting that action concepts are embodied in an effector-related fashion in the motor areas.

If implicit simulations of our own perceptions and actions constitute concepts and word meanings, then their neurocognitive representations should differ for people who perceive and act on the environment in systematically different ways. For example, in a functional magnetic resonance imaging (fMRI) study of action verb processing, premotor activity differed in right versus left handed people, but only for manual action verbs (e.g., *throw*; Willems et al., 2017).

In response to manual action verbs, each group preferentially activated pre-motor areas in the hemisphere contralateral to their dominant hand (Willems et al., 2017). Similar results were reported in the mental imagery task where participants imagined manual and non-manual actions. Thus, consistent with the ECH, the motor system stores action-related aspects of word meaning in systematically different ways for people who act on the world differently, so that they simulate actions correctly when they process action semantics expressed through language (Hickok, 2010; Willems et al., 2017).

1.4.2.2. Evidence for the embodied cognition view from studies of individuals with superior physical functioning

Further evidence in support of the ECH comes from studies examining processing of action words in individuals with superior motor abilities (e.g., athletes) (Beilock, Lyons, Mattarella-micke, Nusbaum, & Small, 2008; Holt & Beilock, 2006; Lyons et al., 2010; Milton, Solodkin, Hluštík, & Small, 2007; Ong et al., 2014; Tomasino, Guatto, Rumiati, & Fabbro, 2012). To fully master an action we have to understand its components and have the components in our muscle memory which can only be achieved through overt skill execution (Beilock, 2008; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). When the brain activity of ballet dancers was scanned using fMRI while they watched their own dance style versus a different dance style, greater activation was seen in a network including the bilateral premotor cortex and right superior parietal lobe in response to their own style versus a new style. This network is thought to support not only the observation but the production of action (Calvo-Merino et al., 2005). This study showed that, in viewing known actions, the brain produces a mental movie of the action's components.

Moreover, the systems used to produce said movements differ in athletes by skill level. Expert golfers showed greater activity than novices in regions closely related to precise visual motor simulation before action execution. This system's recruitment during pre-action routines

suggests that experts go through their specific sequence of motor events before performing a mastered action. On the other hand, novices primarily recruited their basal ganglion regions during pre-action routines indicating said simulation is effortful for them and not yet fully automated as the basal ganglia serves to monitor and correct action execution (Milton et al., 2007).

According to the ECH, individuals with superior athletic skills in a sporting domain should have their sensorimotor systems most strongly activated when perceiving actions/action words in their expertise domain versus everyday actions/action words (Beilock et al., 2008; Holt & Beilock, 2006; Lyons et al., 2010; Milton et al., 2007; Ong et al., 2014; Tomasino et al., 2012). Athletes consistently outperformed non-athletes in comprehension of their domain specific verbs (i.e. by deciding if they were legal actions in a sport or not) (Beilock et al., 2008; Holt & Beilock, 2006; Ong et al., 2014; Tomasino et al., 2012). Unfortunately, these findings may simply show that athletes have a more comprehensive vocabulary surrounding their sport of choice as expertise and domain were conflated in these studies. In a follow up study using novice and expert football players, Holt and Beilock (2006) critically manipulated the extent to which the implied action was football specific. Actions could either be football specific (*a quarterback handing off to a receiver*) or non-football specific meaning a player could perform the action but so could an everyday person (*football player sitting on a bench*). Here both groups responded quicker if a non-specific football action picture matched the preceding sentence. However, only athletes showed this effect for the football specific actions. This ability to differentiate between the same item in different action orientations is driven by embodied knowledge of the sensorimotor characteristics of what one is reading about which is mediated by experience performing said actions (Holt & Beilock, 2006; Lyons et al., 2010).

And finally, earlier I noted that athletes and novices rely on different cognitive and neural mechanisms in mental imagery and overt action production tasks (Milton et al., 2007).

Systematic differences can also be found in the mechanisms experts and novices recruit when comprehending action words they have experience with. Experts, novices and fans of ice hockey completed a sentence picture verification task in an fMRI scanner and whole brain regression was performed. The left dorsal premotor cortex was positively associated with hockey experience and beneficially mediated the impact of hockey experience on language comprehension (Beilock et al., 2008). This finding is consistent with the finding that the left premotor cortex plays a large role in higher level action selection (Lyons et al., 2010). As such it has been shown that experience dependent activation of motor areas when listening to action language is not a byproduct of comprehension but an essential part of effective understanding.

Together all the findings from this section, relating to athletes experience dependent comprehension, suggest evidence for an expertise-specific action embodiment phenomenon in language comprehension as predicted by the ECH.

1.4.2.3. Evidence for the embodied cognition view from studies of individuals with compromised physical functioning

The ECH also predicts that damage to the relevant motor systems should result in circumscribed deficits in action knowledge processing (Hickok, 2010; Mahon & Caramazza, 2008). Evidence to support deficits in action verb processing due to impaired motor function comes from studies of individuals with amyotrophic lateral sclerosis (ALS), and Parkinson's disease (PD) (Bak, Donovan, Xuereb, Boniface, & Hodges, 2001; Boulenger et al., 2008; Daniele et al., 2013; Hickok, 2010; Roberts et al., 2017). Thus, individuals with ALS, a condition caused by a decay of motor neurons, have more difficulty naming and comprehending verbs than nouns (Bak et al., 2001; Hickok, 2010). In a naming task, participants saw 50 black and white photos of objects and actions and were asked to name them in as few words as possible (Bak et al., 2001). In the comprehension task, participants saw 50 pairs of photos of either objects or actions and asked to state which one defined the word on a

card participants were shown (Bak et al., 2001). While naming and comprehension was impaired for both objects and actions for ALS individuals, they performed significantly worse on both measures in relation to verbs in line with their vast motor impairments (Bak et al., 2001; Hickok, 2010).

PD individuals, who suffer from muscle rigidity, tremors, and gait abnormalities due to degradation of their dopaminergic system, also show evidence of a semantic motor effect (Boulenger et al., 2008; Roberts et al., 2017). Parkinson's individuals tend to have greater impairments in their upper versus lower limbs. Roberts et al. (2017) tested their ability to process action verbs relating to differing limbs using a a go/no-go task. Participants read sentences relating to upper (e.g. *throw)* and lower limb (i.e. *kick)* use, with physiological state (e.g. *believe)* verb sentences used as a control condition, as well as non-action fillers. Participants responded with a keypress if the presented word referred to either a physical or mental action, or refrained from responding if it did not. As predicted by the ECH, PD individuals with greater upper limb impairments took longer to respond to upper-limb than to lower-limb verbs or control words (Boulenger et al., 2008; Roberts et al., 2017), showing again that their motor impairments predicted their language impairments.

Evidence for impaired processing of action semantics in individuals with compromised motor abilities might serve as strong evidence in support of the embodied cognition view. However, based on studies with ALS or Parkinson's patients, such a conclusion is hard to make because motor functioning is not the only ability that is weakened. First of all, these conditions are most commonly reported in senior individuals, who are likely to experience negative effects of aging on cognition. Secondly, ALS and Parkinson's are also known to have effects well beyond the motor system including higher-order cognitive dysfunction (Boulenger et al., 2008; Hickok, 2010; Roberts et al., 2017). Therefore, in studies with ALS and Parkinson's individuals, it is not possible to state conclusively that the verb processing deficiency is

attributable solely to motor system dysfunction. In contrast, CP is a neurodevelopmental condition that (a) is present in young individuals and (b) is characterized by both motor and language deficits, but unaccompanied by any other high-level cognitive dysfunction. Thus, studies with cerebral palsied individuals will provide clearer evidence for the alleged association of motor impairment and impoverished processing of action semantics. Consistent with the ECH, I predict that lexico-semantic knowledge should be selectively compromised in these individuals based on their disability topography (i.e., restricted to verbs/actions that individuals cannot enact mentally due to their impaired ability to perform this action in reality).

While evidence for a semantic motor effect in CP is lacking, there is some neural evidence that motor imagery deficits occur in a topographic fashion in individuals with CP. For example, Crajé et al. (2010) used a mental rotation task in which participants with right hemiplegic CP were required to grasp and rotate a hexagonal knob over different angles. While both CP and NTs saw increased grasping error rates as rotation angle increased, CP participants were relatively faster in responding to left-hand compared to right-hand stimuli. The difference in reaction time means CP participants had more trouble judging the handedness and grasping angles of photos involving their affected hand regardless of rotation angle. Neurally, CP participants also had reduced rotation-related negativity (RRN) over the parietal area, which was delayed in onset with respect to NT participants in all trials. Upon correlational analysis, mildly impaired individuals showed a stronger RRN for the rotation of right-handed stimuli than those who were more severely impaired. The results suggest a direct relation between the motor imagery processing and the biomechanical constraints of the participants (Crajé et al., 2010).

In summary, there is a vast amount of evidence suggesting that motor concepts and linguistic concepts are embodied in both able-bodied individuals (Buccino et al., 2005; Glenberg & Kaschak, 2002; Hauk et al., 2004; Hauk & Pulvermüller, 2004; Willems et al.,

2017), and superiorly abled athletes (Beilock, 2008; Calvo-Merino et al., 2005; Holt & Beilock, 2006; Lyons et al., 2010; Ong et al., 2014; Tomasino et al., 2012). Although multiple studies have used PD or ALS as a disease model for exploring theories of grounded cognition relative to action semantics (Bak et al., 2001; Boulenger et al., 2008; Daniele et al., 2013; Kemmerer, Miller, MacPherson, Huber, & Tranel, 2013; Kemmerer, Rudrauf, Manzel, & Tranel, 2012; Roberts et al., 2017), these studies have their limitations. First of all, these conditions are most commonly reported in senior individuals, who are likely to experience negative effects of aging on cognition. Secondly, ALS and Parkinson's are also known to have effects well beyond the motor system including higher-order cognitive dysfunction (Boulenger et al., 2008; Hickok, 2010; Roberts et al., 2017). Therefore, in studies with ALS and Parkinson's individuals, it is not possible to state conclusively that the verb processing deficiency is attributable solely to motor system dysfunction.

1.4.2.4. Evidence against the embodied cognition view

Although there are many studies providing evidence for the embodied cognition views both strong and weak (Hauk et al., 2004; Hauk & Pulvermüller, 2004; Hickok, 2010), many researchers believe that this evidence reflects activation cascading from linguistic representations to motor areas that interface with the conceptual system. The idea is that representations (i.e., linguistic concepts) are represented independently of motor activity (Mahon & Caramazza, 2008).This opposition to embodiment is known in the field as the disembodied view. Some researchers even state simultaneous conceptual and motor activation is simply a learned association (Mahon & Caramazza, 2008). As an example, Hickok (2010) managed to teach people to activate pre-motor areas responsible for index finger movement when they saw middle finger and wrist movements as support to the learned association view.

When studying ERPs related to movement in an attempt to replicate the motion-congruency affect found by Glenberg and Kaschak (2002) and Zwaan et al. (2002), Miller et al. (2018) provided evidence for the disembodied cognition view. Participants made hand or foot responses after reading hand or foot- action verbs. Behavioural responses overall were quicker in compatible (hand- hand) over incompatible (hand-foot/ foot hand) trials. However, the two event-related potential (ERP) measures previously found to be sensitive to the activation of these limbs (i.e. the lateralized readiness potential (LRP) and limb selection potential (LSP)), did not differ significantly when responding to foot versus handed stimuli. Miller et al. concluded that conceptual knowledge did not activate motor areas in a reliable fashion.

A common criticism of the ECH is that motor activation must simply result from post lexical motor imagery (Kemmerer, 2015; Mahon & Caramazza, 2008). In an attempt to disentangle whether language-induced motor activation primarily reflects the retrieval of lexical-semantic information or post-lexical motor imagery as adopted by the disembodied view, Van Elk, Van Schie, Zwaan, & Bekkering (2010) presented participants with action verbs performed by different animal species. Van Elk et al. predicted that if motor activation in language processing primarily reflects motor imagery, we should expect humans to have a stronger motor activation for verbs presented in a human context (*Sam swam*) compared to an animal context (*The fish swam)* because the way in which animals (i.e. fish) swim is fundamentally different than how humans swim. Alternatively, if motor activation in language processing primarily reflects the retrieval of lexical-semantic information, we should expect stronger motor activation for animal over human sentences since animals have differing action capabilities to humans. The results revealed that verbs presented in an animal context elicited stronger early motor activation than verbs presented in a human context. In addition, motor activation as evidenced by beta de-synchronization preceded the N400 by about 70 ms. These

findings make a strong argument for the notion that language induced motor activation primarily reflects the retrieval of lexical-semantic information associated with the verb rather than post-lexical motor imagery of specific kinematics (van Elk, Van Schie, Zwaan, & Bekkering, 2010). The findings are also in line with Ambrosini, Scorolli, Borghi, and Costantini (2012) who found participants were faster responding to manipulation verbs when primed by objects in their actual reaching space as opposed to their perceived reaching space. The fact that reaction times reflected actual reaching ability again rules out the idea that involvement of the motor system in language comprehension is an a posteriori occurring process as suggested by Mahon & Caramazza (2008).

Despite all evidence that the motor system is an integral component of language comprehension, a debate which has yet to be resolved is how to deal with abstract concepts (e.g., beauty) where no sensory and motor activity could reliably correspond to their meaning (Kiefer & Pulvermüller, 2012; Mahon & Caramazza, 2008). .

In the least, the state of evidence surrounding the ECH is mixed and further research needs to be prudent in identifying possible confounds in order to be able to properly credit or discredit the hypothesis.

1.5. Summary of the current state of the research

Individuals with CP, in addition to their motor impairment, commonly also have speech and language deficits in two main areas: phonology and lexico-semantic representations (Pennington, 2008). Phonological deficits occur across the CP population and are caused by incomplete mastery of gross and fine motor skills (Bunton & Weismer, 2001; Kim et al., 2011). Lexico-semantic deficits are not quite as widespread. While some studies report overall deficits in the population (Byrne et al., 1995; Fishman, 2018; Lampe et al., 2014), other research has found lexico-semantic deficits to be most common in CP patients with low intelligence (Pirila et al., 2007) and left hemispheric lesions (Kiessling et al., 1983).

The cause of this deficit is also debated. It could be that since language is learned through statistical extraction (Lev-Ari, 2016, 2017; Saffran et al., 1996), and CP individuals converse less frequently this leads to impoverished lexico-semantic representations. Alternatively, because access to a concept involves partial reinstatement of brain activity during actions the words are typically used to speak about (Kiefer & Pulvermüller, 2012), a CP individual's motor impairments lead them to not have full motor cortex involvement in action word processing leading to impoverished lexico-semantic representations.

1.6. The present research

In my thesis research, I examined lexico-semantic processing in adults with CP. The aim of the completed work was twofold. Firstly, lexico-semantic deficits have been extensively documented in children with this condition but not in adults (Bishop et al., 1990; Chorna et al., 2017; Pennington, 2008; Pennington et al., 2006; Pinto & Gardner, 2014; Sandberg & Hjelmquist, 1996; White et al., 1994). It is an open question whether these deficits persist in adulthood. Considering that speech and language therapy revolves mostly around pronunciation as opposed to word knowledge, it is entirely possible that despite speech therapy as children, adults with CP still have a lexico-semantic deficit. Secondly, I probed the mechanisms causing potential lexico-semantic impairments in adults with CP. I explore two possible mechanisms which explain the deficit independent of phonological deficits. It could be that since language is learned through statistical extraction (Lev-Ari, 2016, 2017; Saffran et al., 1996), and CP individuals converse less frequently this leads to impoverished lexico-semantic representations. Alternatively, because access to a concept involves partial reinstatement of brain activity during actions the words are typically used to speak about (Kiefer & Pulvermüller, 2012), a CP individual's motor impairments could lead them to not have full motor cortex involvement in action word processing leading to impoverished lexico-semantic representations. If the social network mechanism (Lev-Ari, 2016, 2017; Lev-Ari &

Shao, 2017; Theofanopoulou et al., 2017) is the cause of the lexico-semantic deficit in CP, I expect that lexico-semantic knowledge be globally compromised in individuals with CP (i.e., it is not restricted to any specific semantic domain). Alternatively, if the ECH type mechanism is the cause (Bak et al., 2001; Boulenger et al., 2008; Glenberg & Kaschak, 2002; Hickok, 2010; Ong et al., 2014; Roberts et al., 2017; Taylor et al., 2008; Tomasino et al., 2012), I predict that lexico-semantic knowledge be selectively compromised in these individuals based on their disability topography (i.e., restricted to verbs/actions that individuals cannot perform due to their disability).

In the thesis work, I examined performance of CP individuals vs. NTs using two language-processing paradigms. In Experiment 1, participants completed a sentence-reading paradigm where they saw sentences that made sense (Plausible condition: *The first graders had milk and cookies for a snack*) and ones that did not make sense (Implausible condition*: The first graders had milk and truth for a snack*). After each sentence they completed a probe task by deciding if a probe word shown to them was in the previous sentence or not. As participants performed the probe task their ERPs were recorded.

The ERP component of interest in this paradigm was the N400. The N400 ERP component is a negative-going modulation of the electrical activity around 300 to 500 ms and peaking at around 400 ms after stimulus onset. The N400 is believed to reflect processing of semantic information (Kutas & Federmeier, 2000; Kutas & Hillyard, 1980). The magnitude of the N400 component is increased when meanings of targets words are implausible compared to plausible in given contexts. Reduction in the N400 effect has been taken as neural evidence for impoverished lexico-semantic representations (Ardal, Donald, Meuter, Muldrew, & Luce, 1990; Jouravlev & Jared, 2014; Weber-Fox & Neville, 1996). The N400 effect tends to be the strongest over the centro-parietal brain areas (Balconi & Caldiroli, 2011; Byrne et al., 1999; Jouravlev et al., 2016; Kutas & Federmeier, 2000; Kutas & Hillyard, 1980; Nigam, Hoffman,

& Simons, 1992) so I will use the centro-parietal brain areas as my regions of interest (ROIs); see *Figure 2* for an electrode montage.

The goal of Experiment 1 was to establish whether CP participants retained classic N400 responses to semantic implausibility of the same magnitude as in the NT participants (Ardal et al., 1990; Balconi & Caldiroli, 2011; Federmeier, 2014; Jouravlev & Jared, 2014; Kutas & Hillyard, 1980; Nigam et al., 1992). (For evidence that the response may be reduced in certain populations see Jouravlev & Jared 2014). Finding reliable group differences between the two groups (i.e., that only NTs show an increased N400 to implausible sentences over plausible sentences with comparable effect sizes between groups) would provide evidence of the fact that whatever processes the N400 reflects, including semantic processing, these processes unfold in different ways in the CP and NT participants.

Experiment 2 was an identity-priming paradigm where participants completed a semantic decision task while their ERP's were recorded. The component of interest was again the N400. In a priming paradigm, targets that overlap with primes in meaning evoke a reduced N400 compared to targets that do not overlap with primes (e.g., Jared, Jouravlev, & Joanisse, 2017). The goal of this experiment was to determine if individuals with CP have more trouble processing action verbs that are in line with their motor impairments compared to verbs pertaining to actions they could successfully perform. The semantic domains of interest were actions, which require lower limbs to perform (critical condition) and psychological state verbs (control condition). Lower limb action verbs were chosen as the critical condition because CP primarily affects the lower limbs (Bax et al., 2005; Minear, 1956). All target stimuli were verbs, preceded by either an identical prime (Identity condition: *kick-kick*) or a semantically unrelated prime (Non-identity condition: *kick-believe*). Participants were then asked to decide whether the target word was a verb which required lower limb usage, or a verb which corresponded to a mental state in a binary semantic decision task.

Finding reliable group differences between CP individuals and NTs in the size of the N400 and response latency effects across all verb conditions would indicate that consistent with the SNH, lexico-semantic deficits are not restricted to a particular domain in individuals with CP. Alternatively, if group differences in the magnitude of the N400 and response latency effect were only present in the lower limb action verb condition, this pattern of results would provide support for the ECH (i.e., limited motor activation causes impoverished semantic representation of movement related concepts in a topographical fashion).

Chapter 2. Experiment 1: ERP Investigation of semantic processing in individuals with CP versus NTs in a sentence-reading paradigm

In Experiment 1, I examined the performance of CP individuals vs. NTs in a sentence-reading paradigm with a plausibility manipulation while their event related potentials (ERPs) to target words were recorded. Sentences were either plausible (e.g. *The first graders had milk and cookies for a snack*) or implausible (e.g. *The first graders had milk and truth for a snack*). The ERP component of interest was the N400. Reduction of the N400 has been shown in individuals with typical linguistic development when a target word does not make sense in the context of a sentence (Curran, Tucker, Kutas, & Posner, 1993; Federmeier, 2014; Kutas & Federmeier, 2000; Kutas & Hillyard, 1980). Further, there is some evidence that the magnitude of the N400 in response to implausible sentences is reduced in populations with compromised linguistic and/or social abilities (Jouravlev et al., 2019; Pijnacker, Geurts, van Lambalgen, Buitelaar, & Hagoort, 2010) and in non-native speakers (Hahne, 2001; Jouravlev & Jared, 2014). The goal of Experiment 1 was to examine whether there was any evidence for semantic impairment in CP. To the best of my knowledge, semantic processing in individuals with CP using ERP methods has only been studied by Bryne et al. (1995), who found that the CP participant had a reversal pattern in their N400, that is a larger negative deflection to plausible picture-word pairs above their comprehension level. However, the conclusions made by Bryne

et al. (1995) are of limited value because they were based on examination of a single participant. Finding reliable group differences between the two groups (i.e., that NTs show an increased N400 to implausible sentences over plausible sentences but that CP participants do not with comparable effect sizes between groups) would indicate that semantic processing unfolds differently in the CP and NT participants.

2.1. Method

2.1.1. Participants

Four female participants (further referred to as participants SS, AS, TC, and KB) over the age of 18 (*Mean age* = 27.5*, SD = 4.20)* with a diagnosis of CP, who are native speakers of English and had normal or corrected to normal vision, were recruited. All types of CP were included in the study. Exclusion criteria included a comorbid disorder (Autism, Epilepsy, Schizophrenia). Participant SS was diagnosed with Arthrogriposis, which means that her physical impairments and spasticity were caused by contractures in her joints localized primarily to her lower limbs. With a GMFCS of two, she has trouble navigating uneven walking conditions and requires a handheld mobility aid when traveling long distances. Participant AS was diagnosed with spastic diplegia meaning she had highly spastic lower limbs and her upper limbs were affected to a lesser extent. Also with a GMFCS of two, she has trouble navigating uneven walking conditions and requires a balance point when climbing stairs. Participant TC was diagnosed with mixed/atypical spastic diplegia meaning she could experience both stiff and floppy lower limbs and that her upper limbs are affected to a lesser extent. With a GMFCS of four she requires physical assistance or powered mobility in most settings. Finally, participant KB was also diagnosed with spastic diplegia, meaning she had highly spastic lower limbs and her upper limbs were affected to a lesser extent. With a GMFCS of three she has difficulty navigating a variety of settings, she uses wheeled mobility when

traveling long distances and may self-propel for shorter distances. All CP participants were enrolled at Carleton as either undergraduate or graduate students.

The recruitment of individuals with CP was done in a number of ways. First of all, I requested the assistance of the Paul Menton Centre for Students with Disabilities (PMC). The staff of the PMC forwarded a recruitment email to any of their clients who had a CP diagnosis. Recruitment posters were also displayed on campus. CP participants received compensation at a rate of $20/hour for a total of $40.

Eleven neurotypical controls were recruited (*Mean Age* = 21.18, *SD* = 1.40, seven females and four males). They were all native English speakers with normal or corrected to normal vision and no known neurological disorders. From this sample, I identified a sub-sample of 4 NT individuals who were matched to the best of our abilities with CP individuals on age (*Mean Age = 20.75, SD= 0.96)* and gender; see *Table 1* for matching distribution. Given that NT data in this experiment was collected separately from CP participants, identical age matching was impossible and so NT participants are substantially younger than their CP counterpart in some cases. Handedness data was also omitted here for the same reason. Recruiting of the NTs was achieved via the Institute of Cognitive Science's SONA system as all NTs were undergraduate students at Carleton. NTs were compensated with 4 credits for their participation.

A power analysis could not be performed in advance of recruitment, as there were no similar studies to the completed work, which used a special population and reported their effect sizes. However considering the small sample sizes reported by Bak et al. (2001), Neilson and Dwyer (1984), and Roberts et al. (2017) where samples were five participants, five participants, and 25 participants respectively, our sample is small but within the realm of previous work in the field.

Table 1

Matching Criteria of Neurotypicals and CP Group in the Sentence-Reading paradigm

NT Participants			**CP Participants**				
Participant	Age	Gender	Participant	Diagnosis	Age	Gender	GMFCS
AF	21	Female	SS	Arthrogryposis Multiplex Congenita	25	Female	2
ZA	20	Female	AS	Spastic Diplegia	23	Female	2
CD	22	Female	TC	Mixed Spastic Diplegia	32	Female	4
SP	20	Female	KB	Spastic Diplegia	30	Female	3

2.1.2. Materials

There were 120 experimental sentences split into two conditions, with an equal number of sentences in each (60 per condition). The sentences were borrowed from a previous study involving the N400 (Arbel, Spencer, & Donchin, 2011). The two conditions were: semantically plausible English sentences (e.g. *The first graders had milk and cookies for a snack*) and semantically implausible English sentences (e.g. *The first graders had milk and truth for a snack*). Sentences were matched on length in words (*Mean Plausible* =10.52, *SD* =1.05 & *Mean Implausible* =11.53, *SD* =1.65). Target word placement in each sentence was never the terminal word but targets were placed closer to the end than to the beginning of sentences.

A full list of stimuli is available in Appendix A Tables A1-A2.

2.1.3. Procedure

Participants were fitted with a 128-channel HydroCel geodesic sensor cap and were positioned sitting in front of a computer screen and keyboard. The participants were then presented with an instruction page. Participants were verbally instructed to limit movements and not to speak during the sessions. Participants read presented sentences as they came up on the screen word by word and responded whether a probe word presented after each sentence was present or not. The probe word determined whether the stimuli were attended to and kept the participant focused.

Stimulus presentation was automated using PsychoPy (Peirce, 2008). Each sentence was presented in RSVP mode. Each word was shown for 600 ms in the center of the screen in white Arial font with a letter height of 0.1 in relation to the screen size on a grey background. Each sentence was followed by a black fixation point (500 ms) and a probe. The probe word was displayed for a maximum of two seconds. Participants indicated whether or not the probe word was in the sentence they read by pressing the letter P on the keyboard if it was in the sentence or Q on the keyboard if it was not. As soon as participants responded or if no response was made, after two seconds, the next sentence would automatically begin. Sentences were presented in two trial blocks of 60 sentences lasting approximately ten minutes each with breaks between each block.

2.1.4. EEG data acquisition and pre-processing

Electroencephalographic (EEG) activity was recorded using a 128-channel HydroCel geodesic sensor cap and GES 250 Amplifier (Van Benthem, Cebulski, Herdman, & Keillor, 2018). The Net Station software program was used to record and preprocess the data. The GES 250 amplifier samples data at 1000 samples/second: Net Station decimated the data stream to 250 samples/second to reduce processing time.

Electrodes were placed according to the International 10-20 convention, including those placed at Cz, Pz, and Oz, located on the midline of the scalp over central, parietal, and occipital cortical areas respectively. Each active electrode was referenced to the average activity of all electrodes.

2.1.5. ERP analysis

Off-line analysis was performed using EEGLab/ERPLab software (Brunner, Delorme, & Makeig, 2013; Delorme & Makeig, 2004). Following standard procedures in ERP research, the signal was filtered offline to reduce line noise (high-pass: 0.1 Hz, low-pass: 30 Hz and a notch filter of 60 Hz). Independent Component Analysis (ICA) and SASICA a semi-automatic selection/ rejection software were used to identify independent components for artefact correction in the EEG. Stereotypical noise such as eye blinks, lateral eye movements, and cardiac artifacts were identified by examining individual components from the ICA decomposition and were removed. Finally, any trials with amplitudes above 75 mv or below -75 mv were removed. I analyzed a subset of electrodes placed over the centro-parietal areas of the brain. For an electrode montage and locations of electrodes included in the analysis see *Figure 2*.

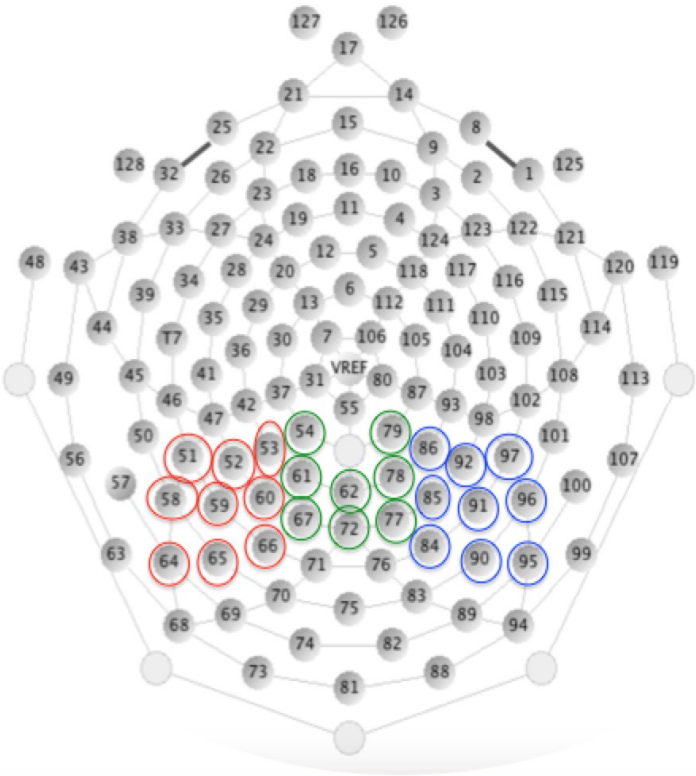

*Figure 2***.** Electrode montage using a 128-channel HydroCel geodesic sensor cap. This figure indicates the three posterior ROIs used in both Experiment 1 and Two. Posterior left electrodes are circled in red, with posterior midline electrodes circled in green, and posterior right electodes in blue.

The continuous EEG signal was divided into epochs over a window from 200 ms prior to the target word onset to 800 ms post onset. The 200 ms window prior to the target word onset was used as the pre-stimulus baseline. To obtain event-related potentials (ERPs), epochs were averaged across trials within a condition for each ROI and participant. For visualization purposes, the responses were further averaged across participants.

The ERP component of interest was the N400, a negative deflection observed at centro-parietal locations on the scalp 300-500 ms post stimulus onset, typically peaking around 400 ms (Kutas & Hillyard, 1980). Given the typical scalp distribution of the N400 analysis was restricted to three ROIs, posterior left (electrodes 53, 52, 51, 58, 59, 60, 64, 65, 66), posterior

midline (electrodes 54, 61, 67, 62, 72, 79, 78, 77) and posterior right (electrodes 86, 92, 97, 85, 91, 96, 84, 90, 95). Further, given the typical time-course of the N400, a 200 ms time-window of interest for analysis (300-500 ms post word onset) was used (Curran et al., 1993; Kutas & Federmeier, 2000; Kutas & Hillyard, 1980; Nigam et al., 1992). The mean amplitudes within this time-window were averaged for each condition, ROI, and participant, and used as dependent measures in the mixed ANOVAs.

2.2. Results

To investigate group differences in semantic processing across different semantic domains, a 2 (*Plausibility*: Plausible, Implausible) x 3 (*ROI*s: Posterior left, Posterior midline and Posterior right) x 2 (*Group*: CP Individuals vs. NTs) mixed ANOVA was fitted to the ERP magnitudes in the N400 time-window. Two of the factors (*Plausibility, ROI*) were within subjects and *Group* was a between subjects factor. Two analyses are reported: One using 11 NTs and 4 CP participants and the second using matched samples of four NTs and four CP participants (see *Table 1* for the criteria on which participants were matched*).* All reported statistics are Greenhouse-Geisser corrected where appropriate with .05 as a significance value with any results between .05 and .08 deemed as marginally significant.

2.2.1. Behavioural analysis

Accuracy rates on the probe task were higher than 75% for all participants and, hence, no participants were removed from the analysis.

2.2.2. ERP analysis

Mean amplitudes of the N400 are shown in *Table 2*. ERP brainwaves evoked by the implausible and plausible targets are shown in in *Figure 3*. When comparing the CP participants to the larger group of non-matched NTs, there was a marginally significant main effect of Group, F (1, 13) = 3.66, p =.08, η_p^2 = .22. ERPs evoked by CP participants were

more negative than ERPs evoked by NT participants. As expected, there was a significant main effect of Plausibility, F (1, 13) = 9.58, p =.009, η_p^2 = .42. Participants' waveforms were significantly more negative in the implausible (M =. -1.00, SE = 0.43) compared to the plausible condition (M = 0.45, SE =0.18). There was no significant interaction between Plausibility and Group, F(1, 13) = 3.30, p =.09, η_p^2 = .20, although the results trended toward significance. However, in contrast to my predictions, CP participants had somewhat more negative deflections in the implausible condition compared to NT participants. Thus, there was no evidence that individuals with CP are impaired in the processing of semantics and specifically semantic implausibility.

Table 2

Mean Amplitudes (μV) with Standard Deviations in brackets of the N400 for NT and CP participants in the Sentence-Reading Paradigm

Group	Group Amplitude	Plausible Amplitude	Implausible Amplitude
NT (n=11)	0.17 (0. 24)	0.47 (0.19)	-0.13 (0.45)
NT (n=4)	0.45 (0.62)	0.97 (0.33)	-0.06 (1.05)
CP	-0.72 (0.40)	0.43 (0.32)	-1.88 (0.74)

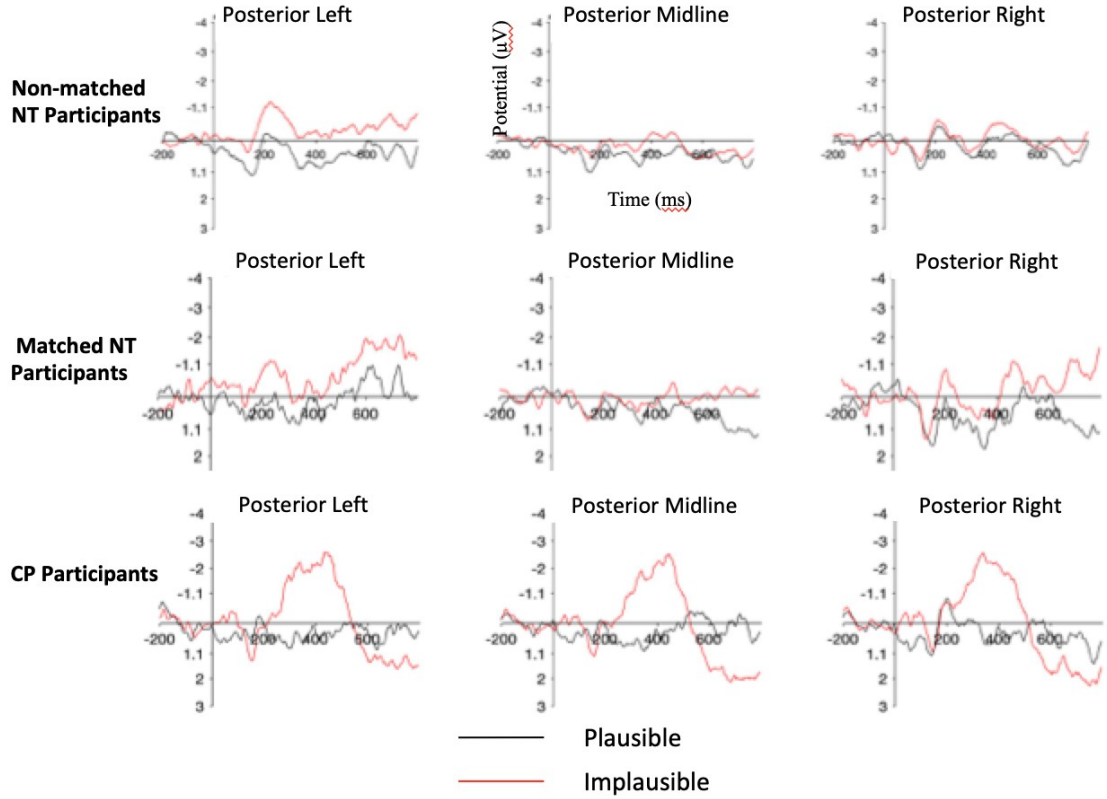

Figure 3. Grand average ERP waveforms elicited to the sentence reading paradigm across the three posterior ROIs between -200 -800 ms post stimulus presentation for non-matched NTs (top), matched NTs (middle), and CP participants (bottom). Black line represents ERPs evoked by targets in the plausible trials while the red line represents ERPs evoked by targets in the implausible trials.

Mean amplitudes of the N400 to implausible and plausible targets in the matched analysis are shown in *Table 2.* There was no significant main effect of Group, F (1, 6) = 2.54, p =.16, η_p^2 = .30.There was a marginally significant main effect of Plausibility on mean amplitudes of the N400 waveform, F (1, 6) = 4.18, p =.08, η_p^2 = .41. Participants' waveforms were somewhat more negative in the implausible (M = -0.97, SE = 0.74) compared to the plausible condition (M = 0.70, SE =0.24). There was again no significant interaction between Plausibility and Group, F(1, 6) = 0.61, p =.47, η_p^2 = .09. In this sample, there was no

evidence to suggest that individuals with CP process semantic implausibility any differently than NT individuals.

2.3. Discussion

With the exception of one case study (Bryne, 1995), no prior research has employed an N400 ERP paradigm to study semantic processing in individuals with CP. In the present study, there was clear evidence of the N400 effect in the CP population. When participants were presented with semantic implausibility they showed increased negative deflections (i.e., a typical N400 response). Furthermore, the negative deflections of those with CP did not significantly differ from NT participants. In fact, negative defections to implausibility were somewhat larger in CPs than the deflections elicited in NTs. Despite prior evidence of a universally present lexico-semantic deficit in adults with CP (Byrne et al., 1995; Fishman, 2018; Lampe et al., 2014), the present study found no evidence that CP and NT individuals process semantic implausibility any differently. These results are in fact similar to a recent study exploring Autism Spectrum Disorder (ASD) that found adults with ASD also had intact N400 responses to unrelated photos despite having lexico-sematic deficits as children (Coderre, Chernenok, Gordon, & Ledoux, 2017). The authors posit that through therapy and practice individuals with mild ASD may have developed compensatory learning strategies that allow them to process language as well as people without ASD (Coderre et al., 2017). Therapy may have also been of benefit to our CP group since as previously discussed widespread semantic deficits are common in children with CP (Levi et al., 2014; Vos et al., 2014).

Other possibilities for the lack of a difference between groups could include the fact that this sample had a higher intelligence and semantic deficits are common in those with intelligence under 70 (Pirila et al., 2007) or that the current sample did not have left

hemispheric lesions (Kiessling et al., 1983). Another possibility is that the deficit is category specific, which will be addressed in Experiment 2.

The implications of this study are two-fold. From a methodological perspective this study expanded from Byrne et al. (1995) in showing that CP participants' disabilities do not compromise EEG data collection. Their EEGs are not inherently noisy unlike a person suffering from epilepsy. Moreover, in this experiment, CP adults had intact and typical N400 responses when viewing senseless sentences. This rejects the idea of a universal lexico-semantic deficit in CP yet again and is consistent with the line of research suggesting that speech language therapy is improving lexico-semantic deficits in children with CP. Intact semantic implausibility responses have been extensively documented in NTs (Curran et al., 1993; Kutas & Federmeier, 2000; Kutas & Hillyard, 1980; Nigam et al., 1992) and certain special populations already, see for example Ardal et al. (1990) and Coderre et al. (2017).

Chapter 3. Experiment 2: ERP investigation of action word semantic processing in individuals with CP versus NTs in an identity-priming paradigm

In Experiment 2, I examined performance of CP individuals and NT controls in a semantic decision task in an identity-priming paradigm. Participants completed a semantic decision task regarding the categorization of action verbs (lower limb verbs) vs. non-action verbs (psychological state verbs), while their event related potentials (ERPs) to target words and reaction times were recorded. The ERP component of interest was again the N400. While the N400 is attenuated by both semantic and identity-priming (Bentin & Moscovitch, 1988; Pickering & Schweinberger, 2003; Rugg, Doyle, & Wells, 1995), compared with semantic priming, identity-priming elicits a much larger reduction in N400 amplitude (Petten, Kutas, Kluender, Mitchiner, & Mcisaac, 1969; Pickering & Schweinberger, 2003).

The goal of Experiment 2 was to examine potential mechanisms of the semantic deficit that has been reported in CP. If CP patients have increased N400s and response latency in the lower limb verb condition, such evidence would support the ECH (i.e., limited motor activation causes impoverished semantic representation of movement-related concepts in a topographical fashion). Alternatively, if CP patients have increased N400s and response latency in both verb conditions compared to NTs this would support a SNH-type mechanism, where CP individuals have globally impoverished lexico-semantic representations.

3.1. Methods

3.1.1. Participants

The same sample of CP participants who took part in Experiment 1 was used here. CP participants received compensation at a rate of $20 per experiment for a total of $40 dollars.

Eleven NTs, native English speakers with normal or corrected to normal vision and no known neurological disorders, were recruited (*Mean Age* = 20.36, *SD* = 3.52, nine females and two males). From this sample, I identified a sub-sample of four NT individuals who were matched with CP individuals on handedness, age (*M= 23, SD= 4.76)*, and gender (see *Table 3* for demographic characteristics). Recruiting of the NTs was achieved via the Institute of Cognitive Science's SONA system so all NTs were students of Carleton (10 undergrads and 1 graduate student). Participants recruited through SONA received 2.5% course credit towards an eligible cognitive science course.

Table 3

Matching Criteria of Neurotypicals and Critical Group in the Identity-Priming Paradigm

NT Participants				**CP Participants**					
Participant	Age	Gender	Handedness	Participant	Diagnosis	Age	Gender	Handedness	GMFCS
AB	20	Female	Right	AS	Spastic Diplegia	23	Female	Right	2
SH	22	Female	Right	SS	Arthrogryposis Multiplex Congenita	25	Female	Right	2
SD	30	Female	Left	TC	Mixed Spastic Diplegia	32	Female	Right	4
AW	20	Female	Right	KB	Spastic Diplegia	30	Female	Right	3

3.1.2. Materials

There were 160 experimental word pairs split into four conditions, with an equal number of pairs in each (40). The conditions were as follows with a *prime-target* setup:

(a) Lower Limb Action Verbs & Identity: *Kick-Kick*

(b) Lower Limb Action Verbs & Non-identity: *Believe-Kick*

(c) Psychological Verbs & Identity: *Believe-Believe*

(d) Psychological Verbs & Non-identity: *Kick-Believe*

Firstly, all target verbs were matched for lexical frequency using the SUBTL norms (Brysbaert & New, 2009) $t(78) = 1.81$, $p = .08$, length in letters $t(78) = 1.61$, $p = .11$, and age of acquisition (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012) $t(78) = 1.45$, $p = .15$ as shown in *Table 3*. Lexical frequency was marginally significant but no other verbs matched well enough to reduce this number. There were 40 verbs per condition: lower limb action verbs and psychological verbs, for a total of 80 verbs. Verbs for each semantic category were chosen

in part from Roberts et al., (2017)'s stimuli. Stimuli were also identified through database searching using Levin (1993). A full list of stimuli is available in Appendix A3.

Table 4

Descriptive Characteristics of the Stimuli. Means and standard deviations (in brackets) are reported.

Condition	**Matching Criteria**		
	Frequency	**Length**	**Acquisition Age**
Lower Limb Verbs	37.59 (77.80)	5.13 (1.32)	6.87 (2.01)
Psychological Verbs	102.03 (210.77)	5.58 (1.17)	7.55 (2.27)

Note: Frequency corresponds to frequency per million word usage. Length corresponds to length in letters.

Secondly, the 80 target verbs were then piloted for expected limb usage. 25 participants read target verbs presented in a randomized order and rated the stimuli on a five point Likert scale as to how certain they were (1 = very uncertain: 5 = very certain) that each verb involved use of one's lower limbs to perform.

Descriptive statistics for each individual item piloted here are presented in Appendix B. Lower limb usage ratings for lower limb action verbs were significantly higher (M = 4.23, SD = 1.19) than for the psychological verb condition (M = 1.60, SD = 1.03), $t(78) = 10.57$, $p < .001$.

Any of the 80 verbs that received a mean lower limb usage rating that was atypical (i.e., 1 SD below the overall mean) were then removed. This resulted in the word *creep* being removed from the lower limb condition. This word was replaced with the word *jog* as it is similar in meaning to the word *run*, which scored high on the lower limb rating scale.

Lastly, each target (e.g., *kick*) was paired with an identity (e.g. *kick*) and non-identity prime (*believe*). Identity primes were the same verbs as targets. Non-identity primes were verbs randomly chosen from the opposing semantic category. This resulted in 160 word pairs over four conditions.

A full list of stimuli is available in Appendix A Table A3.

3.1.3. Procedure

Firstly, informed consent was obtained. Participants were then asked about the characteristics of their social networks as per Lev-Ari (2017). The adapted questionnaire is located in Appendix D. Participants then completed as many practice trials as they needed, displayed in blocks of five trials, for the identity-priming paradigm and the identity-priming paradigm was then administered. Stimuli presentation for the identity-priming paradigm was automated using PsychoPy (Peirce, 2008). All stimuli were displayed to participants on a screen using a grey background and white Arial font with a letter height of 0.1 in relation to screen size along with capitalization of the first letter of primes and targets. Each trial began with a fixation cross, displayed in the center of the screen for 300 ms. Participants then viewed a prime for 600 ms, a blank screen for 100 ms followed by a target word which remained on screen for up to 1500 ms (1.5 s) or until the participant made a key press. Participants were instructed to press P for lower limb targets and Q for psychological targets. While targets were not specially marked and a response mapping issue (i.e. that psychological was not mapped to P), may have occurred participants were accustomed to the layout of the experiment and their task thanks to the unlimited practice trials. Reaction times and accuracy data were recorded. Stimulus presentation was randomized across participants and divided into four blocks by having participants take a break after every 40 trials. A visual depiction of the task can be found in *Figure 4.* NT participants were in the lab for approximately 20-25 minutes.

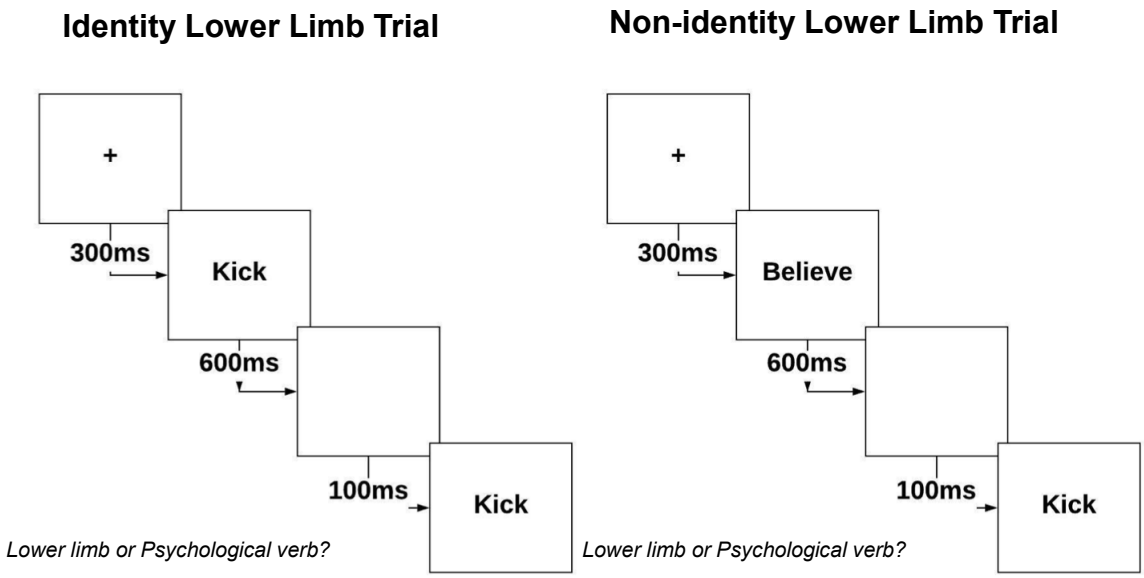

*Figure 4***.** Sample of an identity (left) and non-identity (right) trial with the verb type manipulation.

For CP participants the procedure was the same with two small deviations. After completing their social network questionnaire they were also administered a motor functioning questionnaire. Participants were given scenarios and asked to rate the degree to which they could perform the specified activities independently. This served as a way to quantify the severity of their disability according to the levels specified in the Gross Motor Function Classification Score (GMFCS; see Appendix C). Due to limited time, the self-report questionnaire was used, in lieu of the qualitative observation period version of this assessment (Palisano et al., 1997, 2000; Palisano et al., 2018). CP participants were also in the lab for a total of approximately 90 minutes because for this group Experiment 1 and 2 were administered in the same testing session.

3.1.4. EEG data acquisition and pre-processing

Electroencephalographic (EEG) activity was recorded and filtered according to the protocol described in section 2.1.4.

3.1.5. ERP analysis

Off-line analysis was performed using EEGLab/ERPLab software (Brunner et al., 2013; Delorme & Makeig, 2004), according to the protocol described in section 2.1.5.

3.2. Results

To investigate group differences in action semantic processing across different semantic domains, a 2 (*Verb Type*: Lower Limb Action vs. Psychological) x 3 (*ROI*s: Posterior Left, Posterior Midline, Posterior Right) x 2 (*Group*: CP Individuals vs. NTs) x 2 (*Identity*: Identity and Non-identity) mixed ANOVA was fitted to the ERP magnitudes in the N400 time-window. Three of the factors (*Verb Type, ROIs* and *Identity*) were within subjects factors and *Group* was a between subjects factor. Mean N400 amplitudes were the dependent variable. Two analyses are reported below: one using 11 NTs and 4 CP participants and the second using matched sample of four NT and four CP participants (*Table 3).* All reported statistics are Greenhouse-Geisser corrected where appropriate with .05 as a significance value with any results between .05 and .08 deemed as marginally significant.

To investigate whether N400 magnitude varied as a function of social network size, reaction time and mean difference amplitudes of non-identity-identity trials for each Verb Type and Group were correlated with social network size after collapsing across participants and the three posterior ROIs.

4.2.1. Behavioural analysis

Accuracy. Across all participants, 218 trials (0.09%) were removed because participants failed to provide a response. Mean accuracies of CP and NT participants responses to targets in the four conditions are provided in *Figure 5*.

As expected, there was a marginally significant main effect of Identity when performance of the CP participants was compared with a large non-matched sample of NT participants, F (1, 13) = 4.14, p = .06, $\eta_p^2 = .24$, but not with a matched sample of NT participants, F (1, 6) = 2.79, p = .15, $\eta p^2 = .32$. In the non-matched analysis, participants were much more accurate on identity (M = 0.91, SE =0.02) than non-identity trials (M =0.86, SE =0.03). There was a significant main effect of Group when performance of the CP participants was compared with a large non-matched sample of NT participants, F (1, 13) = 7.02, p =.02, $\eta p^2 = .35$, but not with a matched sample of NT participants, F (1, 6) = 2.88, p = .14, $\eta_p^2 = .32$. In the non-matched analysis, CP individuals (M= 0.82 SE= 0.04) were significantly less accurate on the task than NTs (M = 0.94, SE = 0.02), There was a significant main effect of Verb Type when performance of the CP participants was compared with a large non-matched sample of NT participants, F (1, 13) = 7.80, p =.02, $\eta p^2 = .38$ and a marginally significant effect with a matched sample of NT participants, F (1, 6) = 4.99, p = .07, $\eta_p^2 = .45$. In the non-matched analysis, participants were more accurate when responding to the psychological verb condition (Non-matched: M= 0.90, SE = 0.02;Matched: M= 0.91, SE= 0.04) than lower limb condition (Non-matched: M = 0.86, SE = 0.02; Matched: M= 0.87, SE=0.04).

There was also a significant Group by Identity interaction for the non-matched comparison, F (1, 13) = 6.48, p = .02, $\eta p^2 = .33$, indicating that CP individuals performed significantly worse in the non-identity condition (M= 0.77, SE= 0.05) than NTs (M= 0.94, SE= 0.03), whereas there were no group differences in processing of the Identity condition (M= 0.88, SE= 0.03) *vs* NTs (M= 0.93, SE= 0.02). There were no other significant two-way, three-way or four-way interactions in the non-matched, all Fs < 1.61, all ps >. 23, or in the matched analyses, all Fs < 1.45, all ps >. 27.

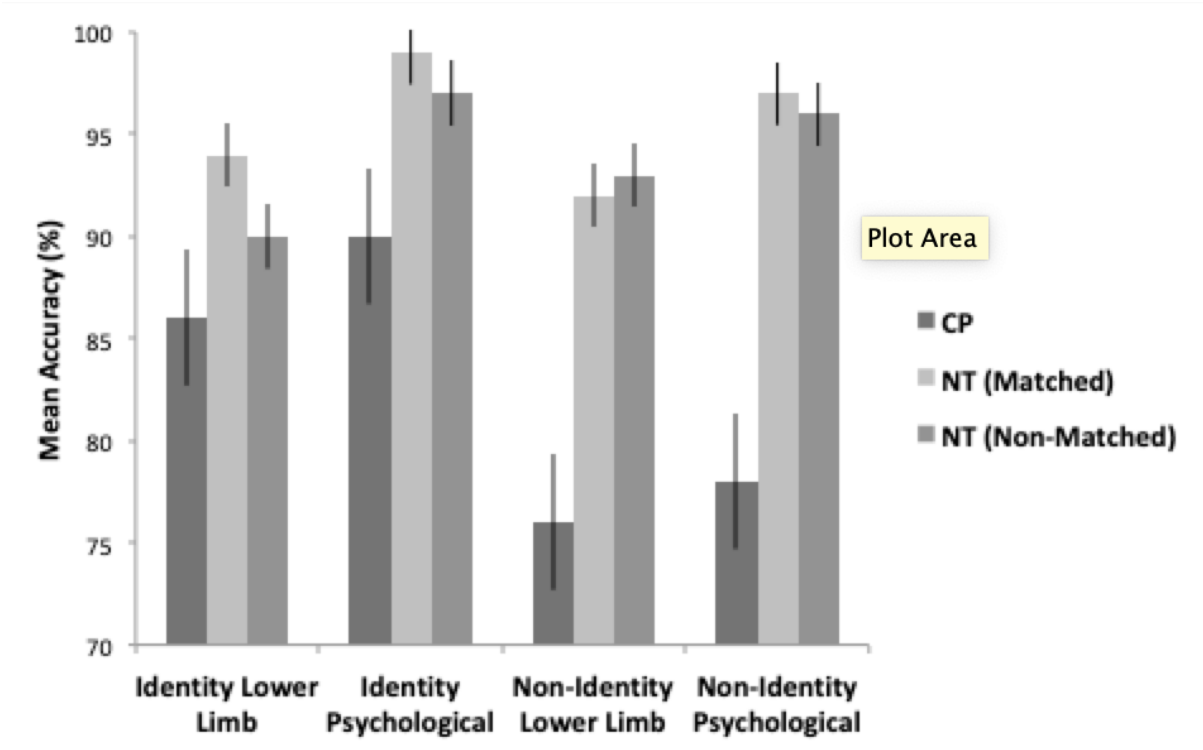

Figure 5. Mean accuracy expressed as a percentage in response to targets in the four conditions. Error bars represent standard errors of the mean.

Response Time (RT). Only response times for correct responses were included in the analysis. This resulted in the removal of 186 (8.5%) trials. Further, outlier RTs (i.e., response times +/- two SD from the mean) were removed prior to analysis. This resulted in the removal of an additional 56 trials. Mean RTs of CP and NT participants to targets in the four conditions are provided in *Figure 6*.

Unlike the expected quickened repetition effect found in the identity priming tasks (Glenberg & Kaschak, 2002; Kaschak et al., 2005), there was no significant main effect of Identity when performance of the CP participants was compared with a large non-matched sample of NT participants, $F(1, 13) = .002$, $p = .97$, $\eta p^2 = .00$, or with a matched sample of NT participants, $F(1, 6) = .51$, $p =. 50$, $\eta_p^2 = .78$. There was no significant main effect of Group when performance of the CP participants was compared with a large non-matched

sample of NT participants, $F(1, 13) = 3.02$, $p = .11$, $\eta p^2 = .19$ or with a matched sample of NT participants, $F(1, 6) = 3.78$, $p =. 10$, $\eta_p^2 = .39$. There was a significant main effect of Verb Type when performance of the CP participants was compared with a large non-matched sample of NT participants, $F(1, 13) = 35.30$, $p <.001$, $\eta p^2 = .73$ and with a matched sample of NT participants, $F(1, 6) = 11.22$, $p = .02$, $\eta p^2 = .65$. Participants had faster response times when responding to the lower limb verb condition (Non-matched: *M= 658.04ms*, *SE = 28.91;*Matched*: M= 642.90ms*, *SE= 34.45*) than psychological condition (Non-matched: *M = 775.68ms*, *SE = 36.98;* Matched*: M= 753.90ms*, *SE=47.14)*.

There was a significant Group by Identity interaction for the non-matched comparison , $F(1, 13) = 6.85$, $p = .02$, $\eta p^2 = .35$, and matched comparison $F(1, 6) = 7.43$, $p = .03$, $\eta_p^2 = .55$. For identity trials, CP participants had slower response times (Non-matched: *M= 793.21ms*, *SE = 60.79;*Matched*: M= 793.21ms*, *SE= 56.36)* than NTs (Non-matched: *M= 641.16ms*, *SE = 36.66;*Matched*: M= 558.53ms*, *SE= 56.36*). In the non-identity trials, means were very similar for CP (Non-matched: *M= 750.65ms*, *SE = 50.66;*Matched*: M= 750.65ms*, *SE= 54.68)* but not NTs (Non-matched: *M= 682.41ms*, *SE = 30.55;*Matched*: M= 661.20ms*, *SE= 54.68*).

There was also a marginally significant Group by Verb Type interaction for the non-matched comparison, $F(1, 13) = 4.32$, $p =. 05$, $\eta p^2 = .25$, indicating that CP individuals had slower response times (*M= 851.33ms*, *SE= 63.33)* than NTs (*M= 700.04ms*, *SE= 38.19)* on psychological trials, whereas there were no group differences in response times for CP individuals (*M=692.54ms*, *SE= 49.51) vs.* NTs (*M= 623.53ms*, *SE= 29.86*) for lower limb trials.

There was a significant Verb Type by Identity interaction for the matched analyses, $F(1, 6) = 10.45$, $p = .02$, $\eta_p^2 = .64$. For identity trials, participants had faster response times

for lower limb verbs (*M* = 617.01ms, *SE* = 33.37) than psychological verbs (*M* = 764.74, *SE* = 48.97). The two-way interactions were qualified by a significant Verb by Identity by Group three-way interaction, $F(1, 6) = 9.10$, $p = .02$, $\eta_p^2 = .60$. While both CP and NTs had slower response times on psychological than lower limb verbs on identity trials, only CP participants had slower response times on psychological (*M* = 828.83, *SE* = 66.09) than lower limb (*M* = 672.48, *SE* = 58.27) verbs on non-identity trials.

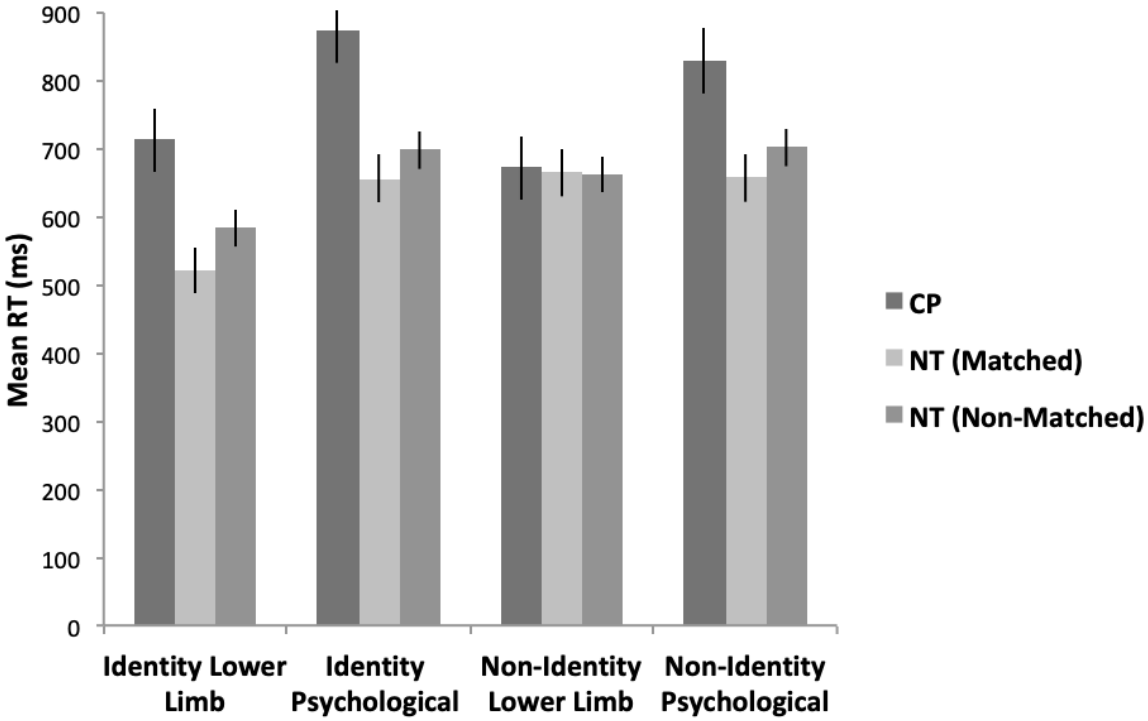

Figure 6. Reaction times for NTs and CP participants to target verbs as a function of Verb Type and Identity. Error bars represent standard error of the mean.

4.2.2. ERP analysis

ERP brainwaves evoked by targets in the four verb conditions for each group in the non-matched analysis are shown in *Figure 7*. There were no significant main effects of Group, $F(1, 13) = 0.69$, $p = .42$, $\eta p^2 = .05$, or Verb Type, $F(1, 13) = .19$, $p = .67$, $\eta p^2 = .01$. The main effect of Identity trended towards significance, $F(1, 13) = 2.29$, $p = .15$, $\eta p^2 = .15$. Participants' waveforms were somewhat more negative in the non-identity condition (*M*= -0.

44, *SE*= 0. 39) than in the identity condition (*M*= 0.20, *SE*= 0.44). All interactions were not significant, all *Fs* < 2.88, all *ps* > .09.

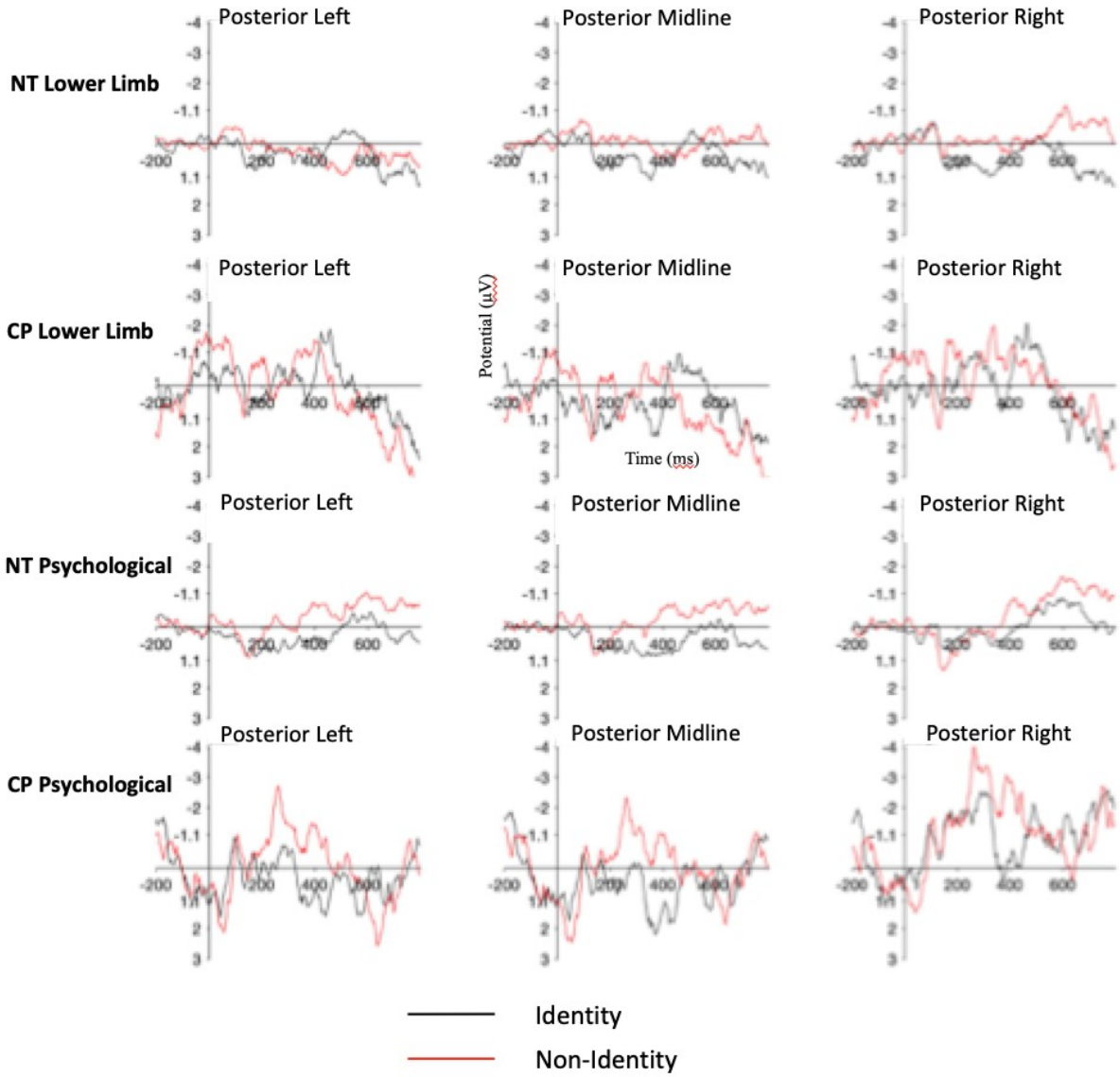

Figure 7 (1-4). Grand average ERP waveforms elicited in the identity-priming paradigm in the non-matched sample across the three posterior ROIs between -200 -800 ms post stimulus presentation for NT Lower Limb ERPs (1), CP Lower Limb ERPs (2), NT Psychological ERPs (3), and CP Psychological ERPs (4). Black line represents ERPs evoked by targets in the identity trials while the red line represents ERPs evoked by targets in the non-identity trials.

ERP brainwaves evoked by targets in our four verb conditions for each group in the matched analysis are shown in *Figure 8.* The main effect of Identity was not significant, $F(1, 6) = 2.01$, $p = .21$, $\eta p^2 = .25$. Participants did not show higher negative amplitudes in the N400 waveforms in the non-identity condition versus the identity condition. The main effect of Verb Type was not significant, $F(1, 6) = .03$, $p = .87$, $\eta p^2 = .01$.CP participants did not show higher negative deflections than NTs either, $F(1, 6) = .11$, $p = .75$, $\eta p^2 = .02$. There were no significant interactions, all $Fs < 2.09$, all $ps > .17$.

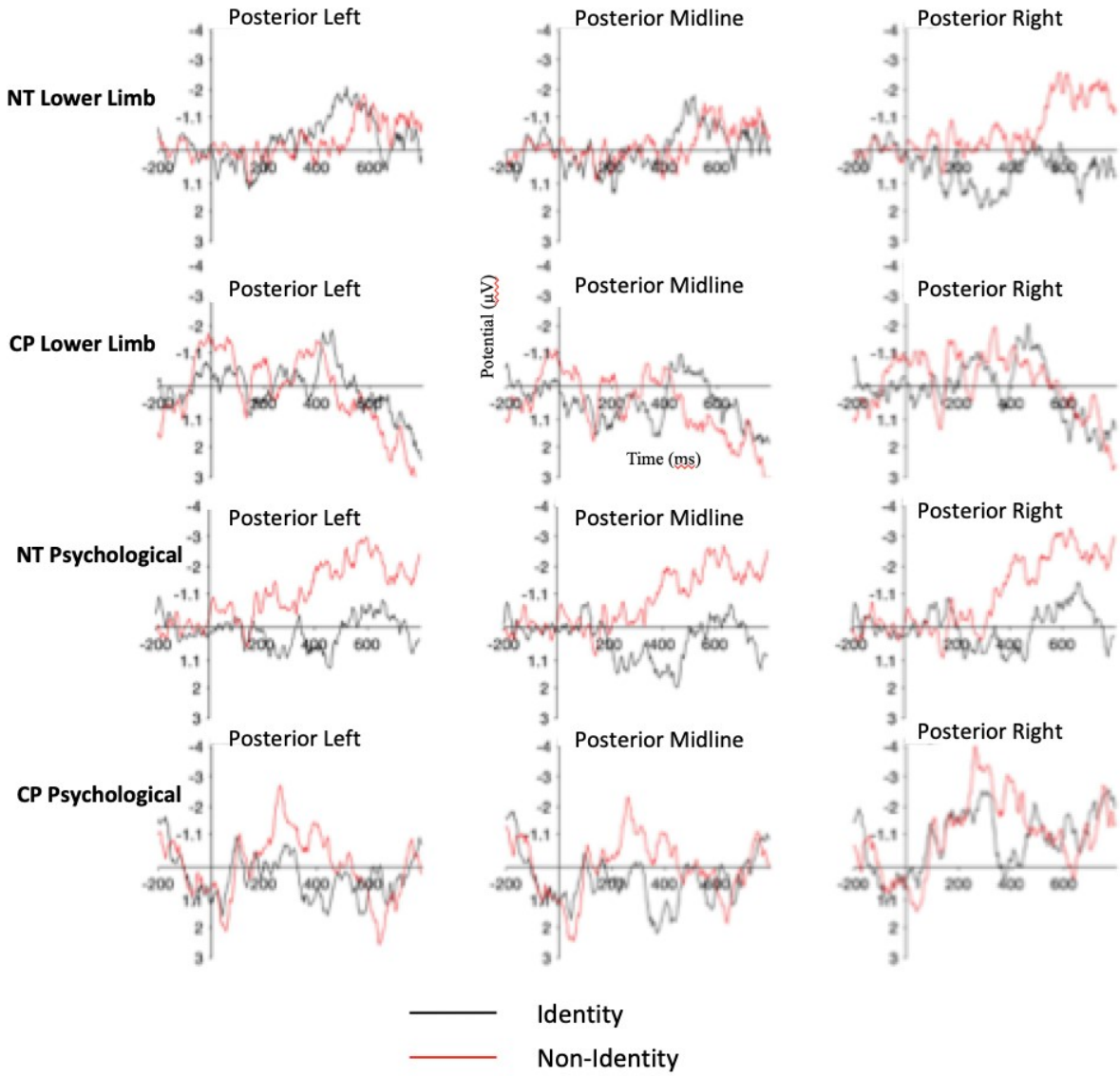

Figure 8 (1-4). Grand average ERP waveforms elicited in the identity-priming paradigm in the matched sample across the three posterior ROIs between -200 -800 ms post stimulus presentation for NT Lower Limb ERPs (1), CP Lower Limb ERPs (2), NT Psychological ERPs (3), and CP Psychological ERPs (4). Black line represents ERPs evoked by targets in the identity trials while the red line represents ERPs evoked by targets in the non-identity trials.

4.2.3. Correlational analysis

Social network size, quantified as the number of interactions participants had in a week which where longer than five minutes and included verbal communication (i.e. no texting) were collected. Descriptive statistics for each group's social network sizes are presented in *Table 5*. Contrary to the predictions of the SNH CP participants actually talked to more people than did NTs. This is because CP participants, in addition to conversing with friends, family and colleagues, also conversed with service providers, a group the NTs did not interact with.

Neither lower limb trial RTs $r(13) = -.09$, $p = .75$ or psychological trial RTs $r(13) = -.04$, $p = .88$ were significantly correlated to social network size.

Neither lower limb trial ERP amplitudes $r(13) = .28$, $p = .31$ or psychological trial ERP amplitudes $r(13) = .23$, $p = .42$ were significantly correlated to social network size.

Table 5

Descriptive Characteristics of the Social Network Sizes of Neurotypicals and CP Participants. Means and standard deviations (in brackets) are reported.

	NTs	**CP**
Average Interactions per Week	12.27 (7.32)	17.00 (7.26)

4.3. Discussion

The non-matched accuracy results showed that in line with previous research all participants were more accurate in the identity over non-identity condition. This makes intuitive sense, as it is easiest to respond accurately to stimuli your brain has already encoded or processed than novel stimuli. The results also indicated that CP participants produced more errors on the task than did controls, this was especially clear in the non-identity

condition. This itself may provide evidence for the idea that Cerebral Palsied individuals have impoverished lexico-semantic representations in multiple domains in line with the findings in Supranuclear Palsy (Daniele et al., 2013). However, when participants were matched to an appropriate control no significant differences emerged. This could either be because there was no true difference but it is necessary to acknowledge that this may also be an issue of sample size and its resulting inability to highlight a difference.

Both reaction time analyses showed no repetition effect and in fact CP participants were slower to respond to identity trials than NTs. During identity trials CP participants were the slowest in responding to psychological verbs. Interestingly, while both CP and NTs had slower response times on psychological than lower limb verbs on identity trials, only CP participants had slower response times on psychological verbs on non-identity trials. This may be an indication that CP participants struggle with abstract concept representations as do individuals with ASD (Caillies, Hody, & Calmus, 2012; Herrera, Jordan, & Veraa, 2006). Social network size was also not a mediating factor in participants' response times to the different verb types although an observable trend was that participants with larger social networks were slightly quicker in responding to identity trials particularly in the lower limb condition. The behavioural results suggest that the lexico-semantic deficits in individuals with CP do not occur in a topographical fashion in line with an individual's physical impairments. The deficits are not consistent with either of the discussed hypotheses. The lack of repetition effect was also particularly odd as it has been widely established and is quite robust (Bentin & Moscovitch, 1988; Pickering & Schweinberger, 2003; Rugg et al., 1995). In running CP participants many voiced frustration that despite practicing, the trials were too quick. By trimming the data as I did for the RT analysis I may have removed an inherent difference in our CP sample: that they were slower to respond overall due to spasticity, further diminishing the ability to show an effect of Identity when compared with NTs who

did show some evidence of quickened responses to identity over non-identity trials particularly in the lower limb conditions.

In the ERP analysis Identity did have a significant effect on N400 waveform mean amplitude, the repetition effect did attenuate the N400 as has been widely reported in previous studies (Bentin & Moscovitch, 1988; Pickering & Schweinberger, 2003; Rugg et al., 1995). From the EEG analysis there was no evidence to suggest that the deficits were specifically related to action knowledge (i.e., lower limb verbs). To further flesh out the potential of the social network type hypothesis in explaining the results I investigated whether N400 mean amplitudes varied as a function of social network size when controlling for Verb Type. It seems in both the lower limb and psychological verb social network size did not play an overly important role either but this may be because social network sizes between groups were similarly large and CP participants had more diversity in their networks due to conversations with service providers (i.e. therapists) which the NTs lacked.

The implications of this study are less clear. The lack of ERP evidence suggests that my prediction that adults with CP have lexico-semantic deficits relating to the typography of their motor impairments because their motor system is damaged does not find much support. The lack of a clear action word processing deficit suggests that pre-motor activity associated with processing action sentences found in NTs (Buccino et al., 2005; Hauk et al., 2004; Hauk & Pulvermüller, 2004) does not overlap with activation in pre-motor activity for processing actions in sentences in those with CP (Tremblay & Small, 2011). This challenges the hypothesis that mirror neurons underlie all language comprehension. It may be that the mirror neuron system (and the pre-motor cortex) is not a necessary component for all types of language comprehension, although this does not imply that it does not play a role in certain circumstances (Tremblay & Small, 2011). Nevertheless, this interpretation is consistent with the results of a recent fMRI study showing a lack of congruency in the involvement of motor/

premotor areas during action observation/execution and action word processing (Postle, McMahon, Ashton, Meredith, & de Zubicaray, 2008). It is also consistent with arguments put forth by those who advocate for disembodied cognition or a less radical view known as the grounding by interaction framework (Mahon & Caramazza, 2008).

Within the grounding by interaction framework, sensory and motor information enriches conceptual processing, and provides it with a relational context. On the disembodied cognition hypothesis, activation of the motor system in tasks that do not require motor system activation must be regarded as supplementary to, and inconsequential for, semantic analysis. In contrast, according to 'grounding by interaction', the instantiation of a concept includes the retrieval of specific sensory and motor information. On this view if one's sensory or motor systems were impaired due to brain damage this would result in impoverished or 'isolated' concepts as has been shown in studies of Parkinson's and ALS patients (Bak et al., 2001; Boulenger et al., 2008; Neininger & Pulvermüller, 2003; Roberts et al., 2017). Sensory and motor information on this view, contributes to the 'full' representation of a concept. The activation of sensory and motor processes during conceptual processing is not necessarily supplementary to or inconsequential for semantic processing.

Chapter 5. Discussion

Much previous work has attempted to establish a connection between damaged motor systems and deficits in action word knowledge (Bak et al., 2001; Boulenger et al., 2008; Neininger & Pulvermüller, 2003; Roberts et al., 2017). An alternative hypothesis is that because individuals interact with fewer people they have depleted semantic knowledge (Lev-Ari, 2016, 2017). However, the current studies involving action knowledge deficits have confounds including using ageing populations and working with populations who have cognitive impairments in addition to their physical impairments which only adds ambiguity to the findings. Examination of performance of CP individuals on action verb processing allows

us the opportunity to test the ECH because affected individuals can have physical impairments of varying severity without necessarily showing any other higher order deficits. CP individuals are also born with their impairments meaning that language acquisition and semantic knowledge must be learned in spite of the physical deficits. If evidence of impaired comprehension skills relating to physical impairments were found this could finally provide un-confounded support for the embodied cognition view of action verb processing.

This study does not include the confounds mentioned above and is the best test of the embodied cognition view of action verb processing to date. This was one of the few studies to examine the persistence of language deficits and more specifically semantic deficits in adults with CP despite the large research body identifying such deficits in children (Bishop et al., 1990; Chorna et al., 2017; Pennington, 2008; Pennington et al., 2006; Pinto & Gardner, 2014; Sandberg & Hjelmquist, 1996; White et al., 1994). Moreover, the study does posit a mechanism or cause for such a lexico-semantic deficit, which is something that few studies save for one, Fishman (2018), have attempted to do.

The aim of the proposed study was twofold. Firstly, I examined lexico-semantic processing in adult individuals with CP. Lexico-semantic deficits have been extensively documented in children with this condition but not adults (Bishop et al., 1990; Chorna et al., 2017; Pennington, 2008; Pennington et al., 2006; Pinto & Gardner, 2014; Sandberg & Hjelmquist, 1996; White et al., 1994). It is an open question whether these deficits persist in adulthood. Considering that speech and language therapy revolves mostly around pronunciation as opposed to word knowledge, it is entirely possible that despite speech therapy as children, adults with CP still have a lexico-semantic deficit. In answering this question I had NT and CP participants complete a sentence-reading paradigm where their N400s were recorded in response to semantically plausible and implausible sentences.

Secondly, I probed into the mechanisms causing potential lexico-semantic impairments in adults with CP. If the SNH (Lev-Ari, 2016, 2017; Lev-Ari & Shao, 2017; Theofanopoulou et al., 2017) were correct, I expected that lexico-semantic knowledge be globally compromised in individuals with CP (i.e., it is not restricted to any specific semantic domain). Alternatively, if the ECH were supported (Bak et al., 2001; Boulenger et al., 2008; Glenberg & Kaschak, 2002; Hickok, 2010; Ong et al., 2014; Roberts et al., 2017; Taylor et al., 2008; Tomasino et al., 2012), I predicted that lexico-semantic knowledge be selectively compromised in these individuals based on their disability topography (i.e., it is restricted to verbs/actions that individuals cannot enact mentally due to their disability to perform this action in reality). In answering this question I examined the performance of CP individuals and NTs in a semantic decision task in an identity-priming paradigm. Participants completed a semantic decision task regarding the categorization of action verbs (lower limb verbs) vs. non-action verbs (psychological state verbs), while their event related potentials (ERPs) to target words were recorded with reaction times. The ERP component of interest was the N400.

5.1 Is there evidence for lexico-semantic impairment in adults with CP?

The results from the sentence-reading paradigm and identity-priming paradigm provide no evidence to suggest that individuals with CP process domain-general semantic anomalies any differently than NTs. When participants were presented with semantic implausibility they showed increased negative deflections (i.e., a typical N400 response). Furthermore, the negative deflections of those with CP did not significantly differ from NTs. Despite prior evidence of a universally present lexico-semantic deficit in adults with CP (Byrne et al., 1995; Fishman, 2018; Lampe et al., 2014), the present study found no evidence that CP and NT individuals process semantic implausibility any differently. These results are in fact similar to a recent study done with participants diagnosed with Autism Spectrum Disorder (ASD) that found adults with ASD also had intact N400 responses to

unrelated photos despite having lexico-sematic deficits as children (Coderre et al., 2017). The authors posit that through therapy and practice individuals with mild ASD may have developed compensatory learning strategies that allow them to process language as well as people without ASD (Coderre et al., 2017). Therapy may have also been of benefit to our CP group since as previously discussed widespread semantic deficits are common in children with CP (Levi et al., 2014; Vos et al., 2014).

5.2. Is there evidence for impaired processing of action semantics in adults with CP?

RTs for both CP and NTs showed no repetition effect. In fact, CP participants were slower to respond to identity trials, with slowest responses for psychological verbs, than NTs. Though both CP and NTs had slower response times on psychological than lower limb verbs on identity trials, only CP participants had slower response times on psychological verbs on non-identity trials. The behavioural results suggest that the lexico-semantic deficits in individuals with CP do not occur in a topographical fashion in line with an individual's physical impairments. The lack of repetition effect was particularly odd as it has been widely established and is quite robust (Bentin & Moscovitch, 1988; Pickering & Schweinberger, 2003; Rugg et al., 1995). One possible explanation for these findings is that spasticity, which can cause movements to take longer to complete, may have artificially lengthened responses for individuals with CP, thus masking an effect of identity or repetition in the paradigm.

From the EEG analysis there was no evidence to suggest that the deficits were specifically related to action knowledge (i.e., lower limb verbs). No clear group differences emerged. What does this lack of clear differences between groups suggest? One possibility is that CP only mildly disrupts motor simulations during verb comprehension, thus CP participants were still able to determine the semantic relations among the action verbs in the identity-priming paradigm (Kemmerer et al., 2013; Silva, Machado, Cravo, Parente, &

Carthery-Goulart, 2016). This view is still compatible with the strong form of the embodied cognition framework and predicts that CP participants would exhibit lower accuracies on a task that required substantially more attention to the motor and effector features of verb meanings. Given that substantially lower accuracies were not found, and due to the severity of our sample's impairment, this purely embodied explanation is unlikely.

If the integrity of the motor system is necessary for action semantics, a clear impairment must be demonstrated in CP. However, if the motor system contributes to, but is not necessary for, action verb processing, then patients may present no clear deficits compared to controls (Silva et al., 2016), or they may exhibit time but not accuracy differences as shown in the completed work. A similar pattern of results was found in stroke patients, who despite having lesions involving some pre-central motor areas, showed no significant correlations between impaired performance on body-part-specific action categories and damage to the corresponding body-part-specific motor areas (Arévalo, Baldo, & Dronkers, 2012; Kemmerer et al., 2013). In a neuro-imaging study proficient verb naming performance of patients whose lesion involved M1 was found while a lack of significant changes in the functional coupling between the left M1 cortex and other brain areas during the verb generation task occurred both for healthy controls and for patients (Maieron, Marin, Fabbro, & Skrap, 2013). Findings are also emerging in studies of ALS patients, who despite having a noun-verb difference do not proportionally differ from the neurotypical population (Papeo et al., 2015). These findings support the view that sensory-motor activity is not necessary, but rather accessory, to linguistic processing (Kemmerer, 2015; Mahon & Caramazza, 2008; Maieron et al., 2013; Tremblay & Small, 2011).

This accessory view would not refute the embodied cognition claim, but would challenge the strong form of this theory. A weak theory however, maintains that it is not always necessary to run motor simulations in left frontal regions in order to appreciate the

nuances of action verbs (Silva et al., 2016); instead, other types of modality-specific semantic representations subserved by other cortical areas may be adequate for many comprehension tasks, as has already been shown in fMRI paradigms for a variety of action verbs (Kemmerer, Castillo, Talavage, Patterson, & Wiley, 2008). Thus, patient populations with so called disability-specific action verb semantic deficits may have such issues not because only their M1 regions relating to arm or leg regions are damaged but rather because of their tendency to have damage/ an underdevelopment in one or more of several other left-hemisphere regions that have been associated with action concepts—specifically, the inferior frontal gyrus, the supramarginal gyrus, and the posterior middle temporal gyrus which have been shown to be reactive in athletes as well (Kemmerer, 2015; Milton et al., 2007).

In the current study it is worth noting that all central ROIs including the central midline ROI were excluded because of lack of reactivity to the N400, and of the posterior ROIs included, in the CP group the posterior midline ROI was the least reactive, which is a sign of maladaptiveness. It seems to suggest that indeed CP patients may have shown intact N400 responses at most ROIs to lower limb verbs not because they have damage to their M1 leg regions but also potentially because they show damage/ less reactivity to semantic underpinning of action verbs in their posterior midline temporal lobes. In the present study, no other regions involved in action verb processing semantics, including the inferior frontal gyrus which is known to be particularly relevant (Urgesi, Candidi, & Avenanti, 2014), were analyzed, which may explain our lack of EEG results between groups. These results allow that motor representations may enrich the concepts of verbs but the simulations are not necessary for the comprehension of verbs (Kemmerer et al., 2013; Silva et al., 2016). In adopting the weak view of the theory, I also leave room for the effects of psycholinguistic factors known to affect language performance such as frequency of word use and social network size (Kuperman et al., 2012; Lev-Ari, 2016; Silva et al., 2016). The

underdevelopment of CP participants' posterior midline and other action-semantics regions may be a result of diminished statistical language pattern extraction from a smaller or atypical social network. Evidence for the weak view of the ECH can be taken from this study and special population studies including Parkinson's disease, stroke patients and those with ALS (Arévalo et al., 2012; Boulenger et al., 2008; Kemmerer, 2015; Kemmerer et al., 2013; Maieron et al., 2013; Papeo et al., 2015; Roberts et al., 2017; Silva et al., 2016). By again having supporting evidence for the weak embodied hypothesis, it seems safe to put to rest the opposing strong embodied hypothesis wherein the motor system is always a necessary component of action language processing and no other factors may interact (Mahon & Caramazza, 2008).

5.3. Limitations

As with any study, these results have their limitations. Perhaps most pertinent is the issue of sample size and diversity and its ramifications for the study's findings. When conducting EEG research in particular, a large sample size is required. The reason for this is twofold. Firstly by increasing sample size, your signal to noise ratio is also increased meaning that your ability to discern meaningful patterns versus artifact in the EEG signal is increased. Secondly, by increasing sample size, variance in the sample is also decreased. Since the N400 component is computed using mean amplitudes, this means that with a smaller sample the variance around my waves is higher than I would like in my CP group. The fact that I found no evidence to suggest that CP individuals process semantic anomalies differently than NT but then failed to find reliable differences in domain specific semantic processes may be an indication that the second paradigm's results were much more subtle than those of the sentence-reading paradigm and our sample size prohibited differentiation of the signal despite having a sample size consistent with that reported by Bak et al. (2001), Neilson and Dwyer (1984), and Roberts et al. (2017) where samples were five subjects, five subjects and 25 subjects

respectively. Our sample diversity may have also been a limiting factor. All of the recruited CP participants were university students and thus they may not represent the "average" CP population. Rather, they may be a high functioning sub-population who have overcome their language impairments leading our paradigm to be incapable of gauging their semantic processing as intelligence is known to affect such semantic deficits (Pirila et al., 2007). It is entirely possible that null results were a consequence of the sample and that if this study were to be run with a larger more diversified sample a different pattern of results may reveal itself. This study should be taken instead as an indication of what is possibly occurring in the general population of CP adults.

EEG methodological time constraints are also of relevance here. The 128-channel caps used in the study dry out in approximately 70 minutes. The first paradigm took upwards of 30 minutes to administer, not including the time required to calibrate the cap. Even though I re-hydrated individual electrodes which displayed high impedance before running the second paradigm (i.e., the critical paradigm), it is entirely possible the net was overall too dry to pick up subtle differences in our critical paradigm.

In Experiment 2 I had a lower limb verb condition and a psychological state verb condition. In finding slowed reaction times to non-identity psychological verbs versus lower limb verbs in CP individuals this was taken as evidence that they have intact action concepts However, lower limb action verbs were the only action verb category. It may be that the psychological verbs were less common, as shown by the lexical frequency t-test, and thus that difference is being captured in the quickness of responses. In order to actually document if an action knowledge deficit exists it needs to be studied more extensively. In identifying these limitations, I can now posit future research opportunities that take these limitations into consideration.

5.4. Directions for future research

To further explore the scope of the lexico-semantic deficit found here, a study similar to Roberts et al. (2017) should be administered using a semantic priming paradigm and a larger, diversified sample size of preferably 20-25 CP and NT individuals while studying temporal regions and the frontal gyrus. The larger sample size will aid in improving the signal to noise ratio and deficit diversity. Further Roberts et al. (2017) had a crucial third stimulus condition, lower limb verbs, psychological state verbs and upper limb verbs. With this additional action verb condition, an important distinction can thus be made, namely whether CP individuals show a general deficit in action knowledge or if they indeed present with a deficit in action knowledge that specifically mirrors disability topography.

A more exploratory goal of the current study that unfortunately could not be investigated because of the small sample size, was to examine individual differences in lexico-semantic knowledge of individuals with CP. Specifically, whether the lexico-semantic deficits relate to severity of participant's gross motor abilities. There is evidence between neurological disorders that, for example, motor neurone disease patients have more pronounced deficits in action verb knowledge than Parkinson's patients which is explained as occurring because motor neurone disease is far more degenerative in nature than early onset Parkinson's (Bak et al., 2001; Boulenger et al., 2008). Never has it been investigated whether the severity of the action verb impairment differs within the same neurological disorder. However, CP offers a rarity in the field by having not only a wide degree of motor symptom severity within its diagnosis but also by having a well established widely used standardized manner in which to quantify those differences in motor symptom severity (i.e. The GMFCS) (McCormick et al., 2007; Palisano et al., 1997, 2000, 2008).

Finally, it is worth exploring the reasons this study suffered from such a small sample size as many special population studies do and propose some potential solutions to the issue.

CP is defined as a disability involving mobility limitation so it is not unreasonable for one to assume this is the exact reason for a low participation rate. Even though I was paying participants 40 dollars a session it may not have been worth a CP participant's effort to participate in the study if they weren't already a student at Carleton. Perhaps one of the most effective ways to increase sample size then would be to remove the need to attend campus at all. There are now so called portable EEG machines, which researchers could transport to the participants instead of the participants having to transport themselves to a lab. A similar portable study design was employed in Kemmerer et al. (2013) and they were able to double their sample size in comparison to the current study.

5.5. Conclusions

Although multiple studies have used PD or ALS as a disease model for exploring theories of grounded cognition relative to action semantics (Arévalo et al., 2012; Bak et al., 2001; Boulenger et al., 2008; Daniele et al., 2013; Kemmerer et al., 2013, 2012; Maieron et al., 2013; Neininger & Pulvermüller, 2003; Papeo et al., 2015; Roberts et al., 2017), this study took a novel approach by considering the influence of a disability (i.e. CP) that occurs at birth and which shows no cognitive impairments in an attempt to limit confounds when studying the effects of motor dysfunction on lexico-semantic representations.

Following recent work, our results are consistent with the line of research suggesting speech and language therapy is beneficial in reducing lexico-semantic deficits in adults with CP (Cameron et al., 2005; Coderre et al., 2017; Eyre, 2007). In the second experiment, no clear differences emerged when CP participants action word processing abilities were compared to NTs. For similar results see also: Arévalo et al. (2012), Kemmerer (2015), Kemmerer et al. (2013) Maieron et al. (2013), Postle, McMahon, Ashton, Meredith, & de Zubicaray (2008) Silva et al. (2016). The results raise the intriguing possibility that in a single word processing task the 'essentialness' of somatotopic feature information for

physical action verb processing may be effector-dependent but also an accessory to linguistic processing rather than a necessity since action simulations may not always need to be imagined (Kemmerer, 2015; Kemmerer et al., 2008; Mahon & Caramazza, 2008). Such a hypothesis aligns with less rigid grounded cognition frameworks that propose a flexible semantic processing system modulated by task effects, effector-specific differences in motor cortex resonance, graded activation of motor versus semantic brain regions, and the necessity of psycholinguistic factors.

The role of motor system integrity in language processing is an important theoretical and clinical issue. The current study is novel in its approach and contributes unique findings to the ongoing debates and research in grounded cognition. The results add to the growing number of studies highlighting the complexity of verb impairments in special populations, and because of the interaction between sensorimotor cortex activation and psycholinguistic factors suggest that strong versions of the embodied cognition hypothesis, stating that motor cortex activity is always required for language comprehension, can be put to rest.

Appendix

Appendix A. Stimuli

Table A1

Stimuli used in Experiment 1. Semantically Plausible Sentences

Sentence	Probe	Target Word
The witch flew off on her magic broom in the night.	stay	broom
The camels moved slowly in the Sahara desert in the heat.	sky	desert
The bowler knocked down all ten pins in one shot.	sailed	pins
Their apartment is on the seventh floor of the building.	house	floor
The champion has a shelf full of trophies from winning.	winner	trophies
Smile to the camera as I take your picture right now.	take	picture
You spread butter on bread with a knife so it covers it completely.	bread	knife
He proposed as he got down on his knees as asked for her hand.	asked	knees
His mother baked a wonderful birthday cake to celebrate.	wonderful	cake
I hope that you are telling me the truth or else.	you	truth
He wrapped the scarf around his neck to keep warm.	mittens	neck
The eagle collected twigs to build its nest in the tree.	guitar	nest
The magician pulled rabbits out of his hat on stage.	ironic	hat
He dried his hands on a paper towel in the bathroom.	change	towel
His dad taught him how to dribble the ball after school.	steel	ball
The cowboy made the lasso out of rope for the rodeo.	lasso	rope
At the campsite, weI built our fire and cooked marshmallows.	cooked	fire
She borrowed makeup from her older sister to use.	borrowed	sister
The poor student was expelled from school the other day.	expelled	school
The boys like playing cops and robbers at school.	cops	robbers

The impatient visitor rang the door bell many times.	legs	bell
The beggar asked for some spare change from me.	love	change
The first graders had milk and cookies for a snack.	someone	cookies
There's nothing like a stroll in the park on a nice day.	floor	park
I take coffee with cream and sugar and extra hot.	chocolate	sugar
The girls got into a pillow fight during their sleepover.	during	fight
He heard someone knocking on the front door the other day.	knocking	door
His angry parents sent him to his room to calm down.	him	room
They celebrated with a glass of fine wine and cheese.	fine	wine
The unlucky gambler lost all of his money at the casino.	lost	money
The immigrant wanted to become a U.S. citizen very badly.	needed	citizen
The mouse ate a large piece of cheese in the trap.	dog	cheese
The prince awakened her with a kiss on the cheek.	grown	kiss
The cows stood on the hill and ate grass all day.	own	grass
Every morning he drinks a cup of strong coffee to start the day.	slide	coffee
The ambulance rushed him to the hospital after his injury.	church	hospital
After running, she drank a gallon of water and felt sick.	drank	water
The tree died after being struck by lightning in the rain.	struck	lightning
My mom makes the best pumpkin pie for desert.	best	pie
The ducks were swimming happily in the pond the other day.	happily	pond
Jane returned the books to the library after she read them.	girl	library
Every morning the children walk their dog down the street.	spoon	dog
You promised you will keep it a secret from her.	fog	secret
The bride's face was covered by a veil at the wedding.	jump	veil
The little lost girl cried for her mother in the dark.	laughing	mother

She marked his birthday on her calendar in excitement.	birthday	calendar
The soldier reunited with his extended family with a big smile.	reunited	family
He liked the scent of her new perfume that she wore.	scent	perfume
Every fall he has to rake the leaves in the rain.	rake	leaves
Let me take your hat and coat at the door.	hat	coat
The surgeon scrubbed up before the operation to be clean.	brown	operation
The fairy turned her into a beautiful princess at midnight.	moon	princess
Don’t put too much food on your plate or you won’t eat it.	walk	plate
The shepherd watched his flock of sheep play in the grass.	safely	sheep
The landlord came to collect the rent on the weekend.	dancing	rent
He was condemned to the electric chair as punishment.	condemned	chair
She blew into the straw to make bubbles with her mouth.	make	bubbles
Grandma stored the homemade jelly in a jar on the shelf.	stored	jar
I saw a large grey elephant at the circus yesterday.	circus	elephant
I watched a very good movie on my television last night.	good	television

Table A2

Stimuli used in Experiment 1. Semantically Implausible Sentences

Sentence	Probe	Target Word
The champion has a shelf full of broom he shows off.	mops	broom
John installed the shelves on the wall using a desert and some screws.	cake	desert
He dried his hands on paper pins in the bathroom.	grandma	pins
His angry parents sent him to his floor to calm down.	science	floor
The boys liked playing cops and trophies in the back yard.	magic	trophies
Arnold likes milk and sugar in his picture in the morning.	morning	picture
The magician pulled rabbits out of his knife and the crowd clapped.	rabbits	knife
The ambulance rushed him from his home to the knees as fast as possible.	home	knees
He wrapped the scarf around his cake to keep warm.	scarf	cake
The first graders had milk and truth for a snack.	graders	truth
For dinner Angela had spaghetti and neck with her family.	style	neck
When the gun was shot it made a nest that was very loud.	arrow	nest
This is like comparing apples and hat if you know what I mean.	run	hat
Every morning the children walk their towel down the street.	clothes	towel
Grandma stored the homemade jelly in a ball and put it in the fridge.	delivered	ball
Today for breakfast I made bacon and rope before school.	bacon	rope
The shepherd watched the flock of fire from afar.	flock	fire
The frightened cat climbed up the sister to avoid the dog.	avoid	sister
The beggar asked for some spare school at night.	beggar	school
He ate his meat with a fork and robbers at the table.	fork	robbers

The ambulance rushed him to the bell as quickly as possible.	drink	bell
The cows stood on the hill and ate change all day.	strong	change
She always says hello with a nice cookies on Tuesday.	university	cookies
I washed my hair with some shampoo and park in the morning.	place	park
You promised you will keep it a sugar from him.	hand	sugar
Jane returned the books to the fight after she read them.	books	fight
Every morning he drinks a strong cup of door to start the day.	start	door
The brides face was covered by a room before the ceremony.	covered	room
The young skater fell on the cold wine and hit his head.	young	wine
My Aunt Ava makes the best pumpkin money in the fall.	pumpkin	money
He liked the sweet scent of her new citizen that was in the air.	truck	citizen
At the door I took his hat and cheese and put it on the rack.	grater	cheese
My little brother put cereal in a plastic kiss in order to eat.	hug	kiss
Don’t put too much food on your grass or you wil be sick.	air	grass
The big oak tree died after being struck by coffee in the rain.	cold	coffee
Your neighbour always greets us with a lovely hospital at the door.	neighbour	hospital
The little boy marched like a wooden water for fun.	marched	water
The bride was escorted up the aisle by her loving lightning on her wedding day.	wedding	lightning
Your mom put these beautiful flowers in a pie so everyone could see.	flowers	pie
This door is not able to open without a pond that fits it.	without	pond

The little girl was lost and scared so she cried for her library to come.	understand	library
To cross the puddle he took a big dog over the water.	near	dog
For lunch today I had a peanut butter and secret sandwich.	there	secret
The man was sentenced to five years in veil for his crime	hope	veil
Every fall my neighbour has to rake the mother in the rain.	February	mother
The unfaithful boy broke her calendar that night.	boy	calendar
He put the leftovers back in the family to eat later.	leftovers	family
The soldier was re-united with his extended perfume after the war.	extended	perfume
The famous cook refuses to publish his leaves for all to see.	all	leaves
Their dog was hungry so they fed him some coat in the afternoon.	hungry	coat
Maria put the beautiful violets in an operation in her living room.	face	operation
In order to cross the lake they used a princess with a motor.	tell	princess
The door was locked so they had to use a plate to open it.	plans	plate
The criminal was sentenced to a year in sheep for their crime.	believe	sheep
Every morning Joe has a warm cup of rent to enjoy.	horizon	rent
She blew into the straw to make a chair for fun.	straw	chair
The frightened dog climbed up the bubbles in fear.	climbed	bubbles
His brother taught him how to dribble the jar in the backyard.	brother	jar
I made a sandwich with elephant and peanut butter.	peanut	elephant
James likes milk and television in his coffee.	milk	television

Table A3

Stimuli used in Experiment 2. Targets with their Identity and Non-identity Primes

Lower Limb			Psychological		
Target	Identity Prime	Non-identity prime	Target	Identity Prime	Non-identity Prime
Dropkick	Dropkick	Hurt	Admire	Admire	Stomp
Flee	Flee	Agree	Adore	Adore	Tread
Hike	Hike	Justify	Please	Please	Limp
Hop	Hop	Insist	Agree	Agree	Flee
Jog	Jog	Pity	Amaze	Amaze	Sidestep
Jump	Jump	Deny	Annoy	Annoy	Walk
Kick	Kick	Believe	Hurt	Hurt	Dropkick
Kneel	Kneel	Ponder	Approve	Approve	Step
Leap	Leap	Desire	Believe	Believe	Kick
Lunge	Lunge	Wish	Deny	Deny	Jump
March	March	Mope	Care	Care	Dance
Patrol	Patrol	Deplore	Dream	Dream	Stand
Prance	Prance	Learn	Envy	Envy	Punt
Roam	Roam	Scare	Forgive	Forgive	Skip
Run	Run	Worry	Frieghten	Frieghten	Sleepwalk
Sidestep	Sidestep	Amaze	Grieve	Grieve	Wander
Skate	Skate	Pretend	Hate	Hate	Balance
Skip	Skip	Forgive	Ignore	Ignore	Pedal
Sprint	Sprint	Shame	Insist	Insist	Hop
Stand	Stand	Dream	Justify	Justify	Hike
Step	Step	Approve	Learn	Learn	Prance
Stomp	Stomp	Admire	Praise	Praise	Bounce
Stride	Stride	Ache	Pretend	Pretend	Skate
Stroll	Stroll	Loathe	Ponder	Ponder	Kneel
Strut	Strut	Haunt	Regret	Regret	Shuffle
Tiptoe	Tiptoe	Obsess	Scare	Scare	Roam
Tread	Tread	Adore	Ache	Ache	Stride
Walk	Walk	Annoy	Wish	Wish	Lunge
Wander	Wander	Grieve	Wonder	Wonder	Drive
Drive	Drive	Wonder	Worry	Worry	Run
Pedal	Pedal	Ignore	Obsess	Obsess	Tiptoe
Punt	Punt	Envy	Support	Support	Swim
Balance	Balance	Hate	Pity	Pity	Jog
Shuffle	Shuffle	Regret	Irritate	Irritate	Squat
Limp	Limp	Please	Shame	Shame	Sprint
Sleepwalk	Sleepwalk	Frighten	Desire	Desire	Leap
Squat	Squat	Irritate	Haunt	Haunt	Strut
Dance	Dance	Care	Loathe	Loathe	Stroll
Bounce	Bounce	Praise	Deplore	Deplore	Patrol
Swim	Swim	Support	Mope	Mope	March

Appendix B. Mean Lower Limb Usage Descriptives

Table B1

Descriptive Statistics of Limb Usage Ratings for each Target Verb used in Experiment 2.

Lower Limb			Psychological		
Target	Mean Rating	SD	Target	Mean Rating	SD
Dropkick	4.52	(.87)	Admire	1.36	(.70)
Flee	4.2	(1.29)	Adore	1.32	(.75)
Hike	4.52	(1.05)	Please	1.64	(1.22)
Hop	4.52	(.96)	Agree	1.40	(.82)
Creep	2.92	(1.41)	Amaze	1.56	0.87
Jump	4.60	(.96)	Annoy	1.68	(1.03)
Kick	4.68	(.56)	Hurt	2.28	(1.21)
Kneel	4.44	(.77)	Approve	1.32	(.69)
Leap	4.48	(1.00)	Believe	1.28	(.79)
Lunge	4.48	(1.16)	Deny	1.20	(.41)
March	4.52	(.96)	Care	1.80	(1.38)
Patrol	3.56	(1.19)	Dream	1.36	(.81)
Prance	4.08	(1.32)	Envy	1.40	(.82)
Roam	3.96	(1.17)	Forgive	1.48	(1.00)
Run	4.60	(1.08)	Frighten	1.64	(.99)
Sidestep	4.20	(1.04)	Grieve	1.64	(1.15)
Skate	4.32	(1.18)	Hate	1.52	(1.00)
Skip	4.48	(.92)	Ignore	1.32	(.75)
Sprint	4.72	(.61)	Insist	1.56	(1.00)
Stand	4.44	(1.00)	Justify	1.44	(.92)
Step	4.32	(1.11)	Learn	1.76	(1.01)
Stomp	4.60	(.82)	Ponder	1.64	(1.08)
Stride	4.28	(1.24)	Praise	1.52	(1.12)
Stroll	4.28	(1.17)	Pretend	1.64	(.86)
Strut	4.32	(1.07)	Regret	1.44	(.92)
Tiptoe	4.56	(.87)	Scare	2.00	(1.29)
Tread	3.76	(1.42)	Ache	2.16	(1.28)
Walk	4.76	(.60)	Wish	1.44	(.77)
Wander	3.64	(1.22)	Wonder	1.80	(1.08)
Drive	3.72	(1.57)	Worry	1.60	(1.08)
Pedal	4.28	(1.21)	Obsess	1.52	(1.05)
Punt	3.60	(1.61)	Support	2.60	(1.44)
Balance	3.88	(1.33)	Pity	1.28	(.61)
Shuffle	4.00	(1.32)	Irritate	1.52	(1.05)
Limp	4.28	(1.17)	Shame	1.64	(1.11)

Sleepwalk	4.12	(1.39)	Desire	1.36	(.81)
Squat	4.48	(.87)	Haunt	1.80	(1.15)
Dance	3.76	(1.51)	Loathe	1.52	(.92)
Bounce	3.80	(1.38)	Deplore	1.68	(1.07)
Swim	4.32	(1.18)	Mope	2.04	(1.24)

Appendix C. Gross Motor Function Self Report Questionnaire

GMFCS-E&R Self Report Questionnaire:
for Young People Aged 12- 18 Years

Please read the following and mark **only one box** beside the description that best represents your movement abilities.

I...

☐ **Have difficulty sitting on my own and controlling my head and body posture in most positions**
and have difficulty achieving any voluntary control of movement
and need a specially adapted chair to sit comfortably and be transported anywhere
and have to be lifted or hoisted by another person or special equipment to move

☐ **Can sit on my own but do not stand or walk without significant support**
and therefore always rely on wheelchair when outdoors
and can achieve self-mobility using a powered wheelchair
and can crawl or roll to a limited extent to move around indoors

☐ **Can stand on my own and only walk using a walking aid** (such as a walker, rollator, crutches, canes, etc.)
and find it difficult to climb stairs, or walk on uneven surfaces without support
and use a variety of means to move around depending on the circumstances
and prefer to use a wheelchair to travel quickly or over longer distances

☐ **Can walk on my own without using walking aids, but need to hold the handrail when going up or down stairs**
and therefore walk in most settings
and often find it difficult to walk on uneven surfaces, slopes or in crowds
and may occasionally prefer to use a walking aid (such as a cane or crutch) or a wheelchair to travel quickly or over longer distances

☐ **Can walk on my own without using walking aids, and can go up or down stairs without needing to hold the handrail**
and walk wherever I want to go (including uneven surfaces, slopes or in crowds)
and can run and jump although my speed, balance, and coordination may be limited

Available from *CanChild* Centre for Childhood Disability Research (www.canchild.ca), McMaster University
GMFCS-E&R modified with permission from Palisano et al. (2008) Dev Med Child Neurol, 50(10), 744-750.

Figure C1. Gross Motor Function Classification Scale Self-Report Questionnaire taken from Palisano et al. (2008).

Appendix D. Social Network Questionnaire

Social network questionnaire

In this questionnaire we would like to gather information about your linguistic interactions. WeI realize that some of the estimates are difficult to make. Please do your best and be as accurate as possible.

Important: When providing estimates for your exposure in a week, keep in mind that your habits may vary considerably depending on the day of the week (e.g., weekday vs. weekend). Please be as accurate as possible and do not simply multiply your estimate for one day by 7.

1) How old are you?

2) With how many people do you converse orally **in a typical week**? (Please only include people with whom you regularly talk for longer than 5 minutes)

3) How many hours do you usually spend on conversing orally with people **in a typical week**?

4) How are the people you converse with **in a typical week** related to you (e.g. friend, colleague, family, service person, neighbor etc.)? Please indicate the relations with an estimate of how many people fall there (e.g., 3 relatives, 10 colleagues etc.).

Number of people	Relation to you

5) Please state the age range of the people with whom you regularly converse **in a typical week** from the youngest person to the oldest person (e.g. 21-60 years). Only include those

above the age of 12.

Figure C1. Social Network Questionnaire- Adapted from Lev-Ari (2017).

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