Involvement of the Intraparietal Sulcus in Sentence Comprehension

An rTMS investigation

by

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ABSTRACT

Semantically reversible sentences, i.e., sentences wherein both characters can potentially perform the given action, have long been used to understand the various mechanisms involved in successful sentence comprehension. Over the decades, studies have established that sentences with non-canonical word-orders such as passive voice sentences are more difficult to process than canonical counterparts such as active voice sentences using psycholinguistic, neuroimaging, lesion-based, and more recently transcranial brain stimulation methods such as transcranial magnetic stimulation (TMS). In addition to understanding the cognitive processes involved, these studies have also attempted to uncover the underlying neural correlates. Various parts of the frontal, temporal, and parietal lobes have been thought to be critical for different functions. In the recent years, the parietal regions have garnered considerable attention. In particular, various studies have found the intraparietal sulcus (IPS) to be involved in the comprehension of semantically reversible sentences, particularly when they have non-canonical word-orders. In this thesis, I attempted to build on this literature and further understand the role of the IPS in sentence comprehension.

More specifically I followed-up on two TMS studies by Finocchiaro and colleagues that looked at reversible Italian active and passive sentences. Online repetitive TMS (rTMS) to the posterior portion of the left IPS (henceforth, l-pIPS) affected only the processing of passive sentences in both experiments. In fact, one of the studies also found an effect on 'passive' pseudosentences, thus, prompting the authors to suggest that the l-pIPS affects passive sentences irrespective of semantic meaningfulness. The authors concluded that this region is likely to be involved in sentence comprehension, particularly at the stage where thematic reanalysis, i.e., a revision of the initially ascribed thematic roles, occurs. However, these studies were unable to discern if these effects were seen on reversible passives due to their reversibility, passive voice, or the non-canonical word-order seen in passive sentences. They also raised questions regarding whether the region is important in

processing only thematic reversibility or is also involved in comprehending reversible sentences without thematic roles (e.g., comparative sentences). I ran three experiments to better understand these factors.

In **Chapter 1** I summarise the literature on the comprehension of reversible sentences. I discuss findings from behavioural, lesion-based, neuroimaging, and TMS studies that have formed the basis of the current thesis. I conclude by bringing to attention some of the questions raised by these studies that I have attempted to answer in the subsequent chapters. In **Chapter 2** I attempted to understand the role of passive voice and reversibility in reanalysis and sentence comprehension. To do this I used a sentence comprehension task while administering online rTMS to the l-pIPS. Participants performed a forced-choice task where they were required to read reversible and irreversible Italian active and passive voice sentences and identify either the agent or the theme in alternate blocks. The experiment showed an effect of rTMS only on reversible passive sentences. While these results are in line with the previous studies, they also draw attention to a critical aspect of comprehension of passive voice sentences. They suggest that passive voice in itself may be insufficient to trigger reanalysis. Instead, it is likely that reanalysis is triggered by the co-occurrence of numerous factors such as voice and reversibility. However, as with the previous studies, this study still does not clarify the role of non-canonical word-order or passive voice *per se*.

In an attempt to distinguish between the two, I ran an rTMS experiment with a sentence-picture verification task in **Chapter 3.** The experiment used reversible active and passive voice sentences in Hindi. The advantage that Hindi offers in this regard is that both actives and passives are typically presented in the agent-theme-action order. Consequently, such passives may not require the reassigning of originally established thematic roles. Stimulation to the l-pIPS showed no effects on these actives or passives. Interestingly, these null results serve as supporting evidence (albeit, weak) that non-canonical word-order may be essential for thematic reanalysis. If passive voice alone, or even a combination of passive voice and reversibility were sufficient to engender reanalysis, stimulation should have had effects on the passives even in the absence of a non-canonical word-order (as seen in the stimuli of this experiment).

Finally, I attempted to understand if the region was involved only in comprehending reversible sentences with thematic role assignment, or also played a role in reversible sentences without thematic role assignment such as comparative sentences (where one of the two characters is the owner of a given property/feature). To do this, I ran the final rTMS experiment reported in **Chapter 4**. Participants received online stimulation to the l-pIPS while performing a sentence-picture verification task. The stimuli sentences consisted of reversible Italian declarative active and passive sentences, and comparative of majority or minority sentences. Comparatives were used because unlike Italian actives and passives, both types of comparatives are identical in word-order and other morphosyntactic features. In an attempt to maintain the visual complexity across stimuli pictures, same pictures were used to depict the relationships in both declarative and comparative sentences. The results of this study are rather puzzling. Unlike previous studies no effects were found on passive sentences. In terms of the comparative sentences, a selective effect was seen on the 'easier' comparatives of majority. These results call into question previous findings which have found an effect on the more 'difficult' sentence type, i.e., the passives. The effect of TMS on the comparatives of majority indicates the involvement of the l-pIPS in sentence comprehension yet again. However, these results to do not clarify what specific features of a sentence the l-pIPS helps comprehend. Moreover, given the consistent effect of rTMS on reversible Italian passives in the previous experiments, and the effect on comparatives of majority, it is possible that the current results may have been confounded by the use of complex stimuli.

Coupled with the findings from the Finocchiaro studies, this thesis establishes the role of the l-pIPS in sentence comprehension. In particular, the results of the two Finocchiaro studies and **Chapter 2** suggest that the co-occurrence of passive voice and reversibility is essential for reanalysis. While the results of **Chapter 3** concur with these findings, they also strongly indicate that these features must co-occur with a third factor, namely a non-canonical word-order, to trigger reanalysis. Lastly, the results of **Chapter 4** clarify the l-pIPS' involvement in sentence comprehension. However, it leaves the exact role of the l-pIPS unclear in comprehending reversible sentences without thematic role assignment. The current thesis has advanced our understanding of some key factors responsible for reanalysis, and its neural correlates. Future studies can aim to understand these factors better by exploiting parallel versions of the same sentence type, and by studying different sentence types in isolation. For example, Hindi passives can be presented in both agent-theme-action and theme-agent-action word-orders. Contrasting such versions may help answer questions pertaining to word-order. On the other hand, studying sentences like declaratives and comparatives in separate experiments or even separate sessions may help simplify stimuli, thereby giving us clearer results.

Chapter 1
Introduction

1.1.Introduction

"Sentence comprehension denotes the cognitive processes speakers of a language must perform in order to distil and understand the meaning of utterances as they unfold in real time" (MacDonald & Sussman, 2009, pp.618). Unsurprisingly, sentence comprehension has interested researchers for decades. However, many questions are still debated, due to the number and the variety of the mechanisms involved, whose efficiency is critical for successful sentence comprehension. These mechanisms span from morphosyntactic processing, i.e., processing factors such as tense or case information (e.g., Rossi, Gugler, Hahne, & Friederici, 2005; Schnitzer, 2014) to thematic role assignment, i.e., the identifying the doer and the receiver of the action in a given sentence (e.g., Caplan & Futter, 1986; Caramazza & Miceli, 1991; Knoeferle, Crocker, Scheepers, & Pickering, 2005); from prosody, i.e., factors such as stress, pitch, etc (e.g., Carlson, 2009; Frazier, Carlson, & Clifton Jr, 2006; and Schafer, 1997) to context, i.e., the specific framework in which a sentence is used (e.g., Gourley & Catlin, 1978; Kaiser & Trueswell, 2004; Olson & Filby, 1972) and working memory (e.g., Just & Carpenter, 1992; Martin & He, 2004; Papagno & Cecchetto, 2019). Of these, thematic role assignment is perhaps one of the most studied.

1.2. Thematic Role Assignment

Simply put, assigning thematic roles means determining the role that each noun phrase in a sentence plays in the event described by the main verb of that sentence. Comprehending very common sentences, such as simple declaratives (noun-verb-noun), for example, requires assigning the roles of agent (i.e., the character/object carrying out the action as denoted by the verb) and theme/patient (i.e., the character/object who receives the action/who the action is performed on) (see Example 1a).

1a) The mother$_{\text{(AGENT)}}$ *cuts the pie*$_{\text{(THEME)}}$. – Active

In Example 1a, *the mother* is the agent, whereas *the pie* is the theme/patient. Sentence 1a is an active voice sentence that follows the typical English subject-verb-object (SVO), and agent-initial order.

Such sentences are relatively easy to process, as their successful interpretation is aided by cues such as canonical word-order (Caplan & Futter, 1986) and semantic/pragmatic constraints (i.e., pies cannot 'cut'; Finocchiaro, Capasso, Cattaneo, Zuanazzi, & Miceli, 2015).

As regards linear word-order cues, languages with canonical (SVO) order, like English and Italian, and languages with preferred subject-object-verb (SOV) order for active sentences, like Hindi, licence the strategy that assigns the role of agent to the first noun (*the mother*, in this case). Semantic cues, on the other hand, are based on encyclopaedic knowledge. In other words, prior knowledge of the world helps us understand that *the pie* in example 1a cannot perform the action of cutting and hence cannot be the agent.

Many studies on sentence comprehension have focused on thematic role assignment, with a particular emphasis on semantically reversible sentences (e.g., behavioural studies: Caplan & Futter, 1986; Caramazza & Zurif, 1976; Grodzinsky, 2000; Kinno, Kii, Kurokawa, Owan, Kasai & Ono, 2017; Wassenaar & Hagoort, 2007; Yano, Yasunaga, & Koizumi, 2017; lesion studies: Magnusdottir et al., 2013; Rogalsky, LaCroix, Chen, & Anderson, 2018; Thothathiri, Kimberg, & Schwartz, 2012; neuroimaging studies: e.g., Bornkessel, Zysset, Friederici, Von Cramon, & Schlesewsky, 2005; Kinno, Kawamura, Shioda, & Sakai, 2008; Mack, Meltzer-Asscher, Barbieri, and Thompson, 2013). The term 'semantically reversible' refers to sentences in which more than one character can potentially fulfil the role of agent and theme/patient (see Example 1b). The scenario of a mother kissing her child is just as likely as the reverse scenario of a child kissing its mother. However, not all potentially reversible sentences are equally plausible, as the likelihood of some events is constrained, at least in part, by pragmatic considerations. The active declarative sentence in the Example 1c is reversible in the sense that both dogs and cats can chase things, but it is pragmatically more likely that a dog would chase a cat than the reverse. The latter event is still potentially reversible, but less likely in real life. Therefore, to be considered completely reversible, a sentence must remain both meaningful and plausible when characters switch thematic roles.

1b) The mother $_{\text{(AGENT)}}$ *kisses the child*$_{\text{(THEME)}}$. – Active

The child$_{\text{(AGENT)}}$ *kisses the mother*$_{\text{(THEME)}}$. – Active

1c) The dog$_{\text{(AGENT)}}$ *chases the cat* $_{\text{(THEME)}}$. – Active

The cat $_{\text{(AGENT)}}$ *chases the dog*$_{\text{(THEME)}}$. – Active

In fully reversible active sentences (like 1b), then, semantic cues are no longer informative and cannot aid in comprehension. However, linear word order cues remain useful and can still help constrain the assignment of the agent role to the first noun.

A more complex situation occurs when syntactic structure is more complex. For example, when the same reversible relationship as in sentence 1b occurs in the context of a passive voice sentence (as in Example 1d), the change of voice entails a change of word order – while active sentences in English follow the canonical agent-initial order, passive sentences follow a theme-initial order. As a consequence, word-order cues become ineffective and can even be misleading.

1d) The child$_{\text{(THEME)}}$ *is kissed by the mother*$_{\text{(AGENT)}}$. – Passive

The mother $_{\text{(THEME)}}$ *is kissed by the child* $_{\text{(AGENT)}}$. – Passive

Since in passive reversible sentences the individual parsing (i.e., comprehending the sentence by identifying its smaller components such as nouns, verbs, phrases) the sentence, cannot rely on either word-order or semantic cues, thematic role assignment is constrained exclusively by syntax. Correct interpretation of passive sentences requires the first noun to be assigned the role of theme and the second noun to be assigned that of agent. In order to do so, the first-pass parsing based on word order heuristics (‘the first noun is the agent’) must be revised and overridden during ‘reanalysis’ (e.g., Bresnan, 2000; Chomsky, 1981; Pollard and Sag, 1994). In other words, thematic reanalysis, i.e., the process of re-evaluating and reassigning the thematic roles assigned during the initial interpretation, is crucial for the correct interpretation of passive reversible sentences.

As a result of their complexity, semantically reversible sentences that do not follow an agent-initial order have been repeatedly documented as being comprehended more poorly by both cognitively intact individuals and people with aphasia (e.g., Bastiaanse & Van Zonneveld, 2005, 2006; Caplan & Futter, 1986; Ferreira, 2003; Grodzinsky, 2000; Meyer, Mack & Thompson, 2012; Schwartz, Linebarger, Saffran, & Pate, 1987). Caramazza and Zurif (1976) were the first to report poor performance on complex centre-embedded sentences (e.g., *The girl that the boy is hitting is tall*) in patients with Broca's aphasia and with Conduction aphasia. Since then, it has been observed that while sentence comprehension is affected in most types of aphasia (Goodglass, Kaplan, & Barresi, 2001), individuals with 'agrammatic' aphasia are particularly susceptible to deficits in processing reversible sentences.

To fully understand these deficits, and more in general the comprehension of reversible sentences, earlier studies used syntactically complex stimuli (e.g., object-cleft sentences like *'It is the girl that the boy hugs.'*). However, it was soon noticed that similar comprehension difficulties were also observed with syntactically simpler structures such as reversible active and passive voice declarative sentences (e.g. Schwartz, Saffran, & Marin; 1980; Ansell and Flowers; 1982). These findings encouraged researchers to use both syntactically complex sentences (e.g. sentences *2a* and *2b*), and syntactically simpler reversible declarative active and passive voice sentences (e.g. sentences *2c* and *2d*) to understand the mechanisms involved in successful sentence comprehension.

(2a) It is the boy that hugs the girl. – Subject-cleft

(2b) It is the girl that the boy hugs. – Object-cleft

(2c) The boy hugs the girl. – Active

(2d) The girl is hugged by the boy. – Passive

Interestingly, the agent-initial bias has also been observed in syntactically simple and complex irreversible non-canonical sentences such as sentences 3a and 3b (Ferreira, 2003).

(3a) 'The doll is hugged by the girl.' – Passive

(3b) It is the doll that the girl hugs.' – Object-cleft

Ferreira found that sentences in which the theme occurred before the agent yielded higher error rates and longer response times (RTs) than sentences in which the agent was first (e.g. declarative active and subject-cleft sentences), regardless of reversibility. Thus, even though semantic reversibility increases the difficulty of a sentence, comprehending reversible and irreversible passives appeared to be more difficult than comprehending semantically reversible and irreversible actives (see Berndt, Mitchum, & Haedinges, 1996 for meta-analysis). In other words, thematic reanalysis appeared to occur to some extent even in irreversible sentences.

More recently, researchers have started to examine the neural underpinnings of thematic role assignment and reanalysis. These studies include both lesion-symptom mapping in individuals with brain damage and neuroimaging studies in neurologically intact and brain-damaged participants.

1.3. Neural Underpinnings of Sentence Comprehension

Lesion and neuroimaging studies in brain-damaged populations, and neuroimaging investigations in cognitively healthy participants, suggest that a complex neural network including frontal, parietal, and temporal regions plays a critical role in thematic role assignment and in processing of complex syntactic structures (e.g., structures with non-canonical word order).

A positron emission tomography (PET) study with healthy participants by Caplan, Alpert, & Waters (1998) documented increased regional cerebral blood flow (rCBF) in Broca's area (BA44) when subjects processed syntactically complex sentences as opposed to propositionally dense sentences (in the experiment, sentences with one proposition vs two propositions). The authors took this result to indicate that this region is involved in sentence comprehension, and in particular in assigning meaning via the analysis of syntactic structure.

In another study that used voxel-based lesion symptom mapping (VLSM) (Thothathiri et al., 2012) a robust association was found in an aphasic sample between damage to left temporoparietal areas (Brodmann's Areas 22/39/40) and poor comprehension of semantically reversible sentences. This finding led the authors to suggest that temporoparietal regions may be crucial for thematic role assignment.

Other studies found additional focal activations. For example, in an fMRI study of sentence-picture verification in healthy volunteers, Mack et al., (2013) found that passive sentences elicited more activation than active sentences in the left posterior-temporo-occipital regions, and bilaterally in the inferior frontal gyrus (IFG). These findings were in line with previous studies implicating the left temporal cortex in verb-argument integration (see Friederici, 2011; and Thompson & Meltzer-Asscher, 2013). Based on previous studies, Mack et al. correlated the temporal-occipital activation to verb-argument structure integration, and the IFG activation to morphological processing, semantic/pragmatic processing, or processing of complex syntax. Due to the types of stimuli used in the study, they suggest that activation in the anterior foci could be indicative of the involvement of IFG in processing complex syntax. This view is supported by other studies (see Ben-Shachar, Hendler, Kahn, Ben-Bashat, & Grodzinsky, 2004).

In addition to the activation seen in the IFG, many studies of syntactic processing have also shown activation in the intraparietal sulcus (IPS). For example, in an fMRI study by Tettamanti et al (2005) where participants passively listened to action-related sentences in Italian such as *Afferro il* *coltello* (I grasp the knife) and other abstract sentences like *Apprezzo la sincerita`* (I appreciate the sincerity), a selective activation of the left IPS was seen only for action-related sentences and not abstract sentences. In another study by Prat, Keller, & Just (2007), participants performed a visual comprehension task comparing active-conjoined and object-relative sentences. They read the given sentence and answered a true or false question. These sentences were further divided into subcategories of low and high-frequency (determined by frequency of the nouns used in the sentences). Participants showed greater activation of the parietal region (including the IPS) only in the low-frequency noun condition, possibly suggesting the parietal region's involvement in semantic processing. Participants also showed greater activation in the parietal region for object-relative sentences rather than in active-conjoined sentences. Studies by other groups have also shown an increase in activation in the intraparietal region while processing morphosyntactically ungrammatical sentences (e.g., Kuperberg, Holcomb, Sitnikova, Greve, Dale, & Caplan, 2003), and long sentences with and without anomalies (e.g., Tune, Schlesewsky, Nagels, Small, & Bornkessel-Schlesewsky, 2016).

While the above-mentioned studies have seen activation of the left IPS in both syntactic and semantic processing, other studies have that have found the region to be more involved in syntactic processing. For example, in an fMRI study, Bonhage, Mueller, Friederici, and Fiebach (2015) found an activation of the left IPS only for jabberwocky sentences and not regular sentences. The authors argue that these activation patters are based on the availability of syntactic versus semantic cues in the predictive context. Since jabberwocky sentences contain lesser semantic information than regular sentences, the authors interpret the activation in these regions to be reflective of prediction based on syntactic information. In other words, this study implicated the and IPS in sentence comprehension, particularly in the context of syntactic processing. In another fMRI study, Newman, Just, Keller, Roth, & Carpenter (2003) found that activation in the left IPS was modulated by the processing of different syntactic structures (in this case combined active and object relative sentences). The authors posited that one potential explanation for the region's involvement in language comprehension could be that it generates the spatial structure required to map on the thematic roles of the sentence. In another fMRI study by Bornkessel et al (2005), German-speaking participants performed a sentence-picture verification task that required identifying the agent and the theme in subject-initial and object-initial sentences. They found increased activation in the IFG and the IPS when participants were required to process object-initial sentences but not subject-initial sentences, suggesting that these regions are specifically involved in processing non-canonical word-order. Results were replicated in a subsequent study (Bornkessel-Schlesewsky et al, 2009). Similar findings were reported in an fMRI experiment by Kinno et al (2008), who compared Japanese canonical/subject-initial active, noncanonical/subject-initial passive, and noncanonical/object-initial scrambled sentences using a sentence-picture verification task. They found increased activation of the left IFG and IPS for passive and for scrambled sentences.

These studies converge in suggesting the involvement of a frontoparietal network – specifically including the IFG and IPS – in sentence comprehension, particularly in thematic role assignment and reanalysis while processing syntactic complex sentences. Interestingly, these regions have also been implicated in working memory studies (e.g., Fiebach, 2005; Kuhnke et al., 2017; Makuuchi et al., 2013, Makuuchi et al., 2009).

In recent years, neurostimulation studies using transcranial magnetic stimulation also contributed to the understanding of the mechanisms underlying the comprehension of reversible sentences. This literature is discussed below in section 1.4.

1.4. TMS and Sentence Comprehension

Transcranial Magnetic Stimulation (TMS) is a non-Invasive Brain Stimulation technique that induces electrical currents within the cortical regions of the brain by means of magnetic pulses generated by a coil placed over the scalp. When TMS is applied in continuous trains, it is referred to as repetitive TMS (rTMS). rTMS can increase or decrease neuronal excitability, depending on parameters such as pulse frequency and stimulation intensity. Low frequency rTMS (usually between ~1Hz and below 5Hz) tends to decrease cortical excitability, whereas higher frequencies (usually between 5Hz to 20Hz) tend to increase it (Rossi et al., 2009). TMS is primarily administered via monophasic and biphasic pulses. The former is a unidirectional pulse that in generally used in single pulse TMS (Sommer et al., 2018). Biphasic pulses on the other hand are bidirectional. They are frequently used in rTMS protocols as they are able to achieve higher stimulation frequencies (Wassermann et al., 2008). It can be used to study non-brain-damaged individuals while using them as their own controls, thereby increasing experimental power and retest reliability. Furthermore, it also helps avoid confounding variables such as compensatory cortical plasticity that can be seen in patients with brain lesions (Lauro et al., 2010). TMS is considered safe when used according to recommended guidelines (Kroptov, 2016; Merabet & Pascual-Leone, 2019; and Rossi et al., 2009). Due to its non-invasive nature and limited side effects rTMS is increasingly used in language research with both clinical and non-brain-damaged populations (e.g., Naeser et al., 2005; Thiel et al., 2013).

In terms of language research, TMS was first used by Pascual-Leone (1991) to induce speech arrest in pre-surgical patients with epilepsy. After that it was used to understand the effects of speech perception on the motor system in various studies (Fadiga, Vraighero, Buccino, & Rizzolatti, 2002; Sundara, Namasivayam, & Chen, 2001; Watkins, Strafella, & Paus, 2003). While Sundara et al., found that the motor evoked potential (MEP) size of lip muscles increased upon visual perception of speech requiring lip movements, Watkins et al., found similar results during auditory and visual perception of speech. Other TMS studies have shown a close link between action words and motor programmes when TMS is used as a measure of functional connectivity (Pulvermuller, Hauk, Nikulin, & Ilmoniemi, 2005). In addition to using TMS to understand the relationship between different aspects of language and the motor system, it has also been used in aphasia studies. For example, Knecht et al (2002) used TMS to study language lateralisation. They found that reorganisation of language functions in the homologous regions after damage to a given brain region was likely to be dependent on pre-morbid lateralisation. TMS has also been used in the context of aphasia rehabilitation. For example, Coslett and Monsul (1994) found a marked improvement in accuracy after administering single-pulse TMS online to right temporo-parietal regions of aphasia patients with left hemispheric regions. Since then, TMS has been used in and found to be effective to some extent in several aphasia rehabilitation studies (e.g., Martin et al., 2004; Naeser et al., 2005a, b; Winhuisen et al., 2005).

Another aspect of language that has been investigated using TMS is sentence comprehension. In the context of the current thesis, we focus on this aspect of TMS and language. When it comes to studying the neurofunctional correlates of sentence comprehension, TMS has three major advantages as compared to examining individuals with brain lesions. First, it can be applied to very small portions of the scalp. Consequently, it allows one to interfere with very specific cortical regions, and thereby to investigate specific behaviours putatively underpinned by those regions. This can help establish causal links between a region and a behaviour (Sliwinska, Vitello, & Devlin, 2014; Paus, 2005; and Sack, 2006). Second, TMS administered during a single session or across a short time span across two-three sessions perturbs the activity of the stimulated area only temporarily, thus giving the opportunity to measure the short-term effects caused by these changes (Sliwinska et al., 2014). Due to their transient and reversible nature, TMS paradigms often also allow one to observe and measure behaviours before, during, and after perturbation. In other words, the same participant can be his/her own control. Of course, one caveat that comes with this advantage is the repeated exposure to stimuli or similar experimental conditions. This may lead to practice effects in some cases. Lastly, while brain lesions (of whichever nature) tend to involve large cortical and subcortical structures, TMS is applied to a small cortical area, and thus may have a more circumscribed effect on specific cognitive skills. A good example of this is the use of TMS over Broca's area to cause a speech arrest (e.g., Aziz-Zadeh, Cattaneo, Rochat, & Rizzolatti., 2005). For the reasons listed above, TMS has become a popular tool for exploring the neural bases of cognitive processes in general, and sentence comprehension in this particular case. Based on the existing neuroimaging and lesion literature on sentence comprehension (some of which has been discussed above), several TMS studies have focused on the frontal regions.

1.4.1. TMS and Frontal Regions in Sentence Comprehension

A study by Sakai, Noguchi, Takeuchi, & Watanabe (2002) implicated the inferior frontal gyrus (IFG) in syntactic processing. They administered paired-pulse TMS online, i.e., while participants read irreversible Japanese (correct or syntactically/ semantically anomalous) sentences and judged whether a sentence was either (i) syntactically correct or incorrect; or (ii) semantically correct or incorrect. Results showed that TMS to the IFG reduced RTs selectively for the syntactic judgement task. Interestingly, TMS had similar effects on both grammatically correct and anomalous sentences. Based on these results, the authors suggest that the IFG could be relevant for identifying both syntactic anomalies and grammatical correctness.

Uddèn et al (2008) obtained similar results using artificial syntax in an offline rTMS study, in which participants received stimulation prior to the experiment. A continuous biphasic pulse train at 1 Hz to the left IFG (BA44/45) was administered. Stimulation resulted in increased rejection rate and faster reaction times for ungrammatical items.

These studies highlight the role of the IFG in syntactic processing in general. As mentioned above, comprehension of reversible sentences with atypical word order often relies on syntactic reanalysis. Additional studies have focused on the role of the IFG in processes crucial for reanalysis, such as word reordering and argument prediction.

Kuhnke et al (2017) administered 5 pulses of online rTMS at10 Hz to the posterior IFG (pIFG). Participants were presented with German sentences (where subject-initial is the typical order, and object-initial the atypical order) that differed in the distance between the argument and the verb (short or long) and reordering demands (subject-initial vs object-initial argument order). TMS was administered at two points in time: i) an early point, at the onset of the argument, i.e., when the sentence was encoded in WM; ii) a late point, at the onset of the main verb, when verb and argument would be linked. Stimulation selectively affected performance on long-distance sentences (impaired performance on object-initial long-distance sentences, facilitated performance on subject-initial long-distance sentences). The authors suggest that these results highlight the crucial role of pIFG in argument reordering, at least in long-distance dependencies. Given that TMS affects performance at both time points, the authors argue that the region is crucial to reorder arguments and, more specifically, that the reordering of arguments occurs as soon as they appear in a sentence (see also Bornkessel and Schlesewsky, 2006; Bornkessel-Schlesewsky et al., 2009). These results concur with and extend previous data showing a correlation between reordering demands (atypical vs. typical argument orders) and left pIFG activation (Ben-Shachar et al., 2003; Friederici et al., 2006; Kim et al., 2009).

More recently, TMS has been used in combination with other methods. Kroczek et al (2019) used the TMS-EEG co-registration technique to understand the role of the pIFG in sentence comprehension. Participants received online TMS to the pIFG – 3 pulses of at 10 Hz – at verb onset. They were presented with short German sentences (pronoun-verb-article-noun) in a 2x2 design with the factors semantic expectancy (low vs high cloze probability) and syntactic gender (correct vs incorrect). TMS to the pIFG elicited a frontal positivity approximately 200ms after verb onset but did not affect ERPs or behaviour on the last noun of the sentence. The authors attribute this outcome to the fact that the effects of TMS are restricted to the verb position and are already washed out when the noun occurs. They conclude that, when processing verbs in sentential context, frontal regions play a role in predicting an upcoming noun.

These studies establish the role of the IFG in syntactic processing and sentence reanalysis. However, as seen in the previous sections, the IPS has also been gaining increasing attention as an important player in sentence comprehension. TMS studies focusing on these parietal regions point towards their involvement in reanalysis.

1.4.2. TMS and Parietal Regions in Sentence Comprehension

One of the earlier studies was conducted by Lauro, Reis, Cohen, Cecchetto, & Papagno (2010). They stimulated the IFG (BA44) and the inferior parietal lobule (BA40) at a frequency of 1Hz during either a sentence/picture matching task, or a sentence/picture verification task. Three types of sentences were used: i) short sentences (these included actives, passives, and datives), ii) long but syntactically simple sentences (i.e., sentences without long-distance dependencies), and iii) syntactically complex sentences (i.e., sentences with long-distance dependencies – relative clauses in right peripheral position and relative clauses in centre-embedded position). Sentences were presented auditorily and pictures were presented on-screen 1000ms before the sentence ended. rTMS to the IFG (BA44) reduced accuracy only on syntactically complex sentences. rTMS to inferior parietal lobule (BA40) reduced accuracy on long but syntactically simple sentences, and on syntactically complex sentences. Stimulation to the inferior parietal lobule (BA40) only affected sentences in which word order was crucial.

More recently, a study by Finocchiaro et al (2015) implicated the left IPS in the comprehension of reversible sentences. During a sentence-picture matching task that used active and passive declarative sentences, three trains of biphasic pulses at 5Hz were administered to the anterior, middle, or posterior portion of the left IPS. A selective increase in response accuracy for reversible passive sentences was observed only upon stimulation of the left posterior IPS (henceforth l-pIPS), and not of the other two regions. The authors took this result to show that the l-pIPS is involved in thematic role assignment and proposed that this region is critical for the reanalysis of reversible passive sentences, i.e., that it intervenes when noncanonical word-order in passive sentences must be reanalysed to complete correct interpretation of the sentence.

These results were supported in a follow-up study by Finocchiaro, Cattaneo, and Miceli (submitted). In this study, three trains of biphasic pulses at 5Hz were administered to the left pIPS. Stimuli consisted of active (e.g., *La ragazza abbraccia il ragazzo* (The girl hugs the boy)) and passive (*Il ragazzo è abbracciato dalla ragazza (The boy is hugged by the girl)*) sentences and of 'active' pseudosentences (e.g., *Il cotro purfa il trilo*) and 'passive' pseudosentences (e.g., *Il trilo è purfato dal cotro*). During a forced-choice task, participants were asked to read a sentence or a pseudosentence and to pick the agent by deciding between two nouns/pseudonouns written below the sentence/pseudosentence. rTMS facilitated responses to passive sentences and passive pseudosentences. The effect of rTMS on passive sentences therefore replicates the results by Finocchiaro et al (2015). The effect on passive pseudosentences was attributed to the fact that, despite being semantically meaningless, these stimuli are 'reversible' in that they require encoding proto-agent and proto-theme roles (Dowty, 1989, 1991), and that such proto-roles are semantically unconstraind. On this account, then, passive sentences and pseudosentences share the need for reanalysis, and therefore recruit the left pIPS for interpretation.

1.4.3. Online TMS in Sentence Comprehension

As seen in the previous section, most studies on sentence comprehension use online TMS protocols. In the context of sentence comprehension studies, such protocols offer many critical advantages. First, TMS offers very high temporal resolution, in the order of hundreds of milliseconds (Bergmann et al., 2016, Devlin and Watkins, 2008), thereby helping measure behavioural changes in real time (Siebner, Hartwigsen, Kassuba, & Rothwell, 2009). Second, its effects are distinct from those of offline TMS. Offline TMS may elicit changes lasting between 30-50 minutes (Siebner and Rothwell, 2003; Wischnewski and Schutter; 2015). By contrast, online rTMS bursts are too short to result in adaptive reorganisation (Hartwigsen et al., 2015; Pascual-Leone, Walsh, & Rothwell, 2000; Walsh & Cowey, 2000). Especially in the case of high-frequency online rTMS bursts, cortical activity is thought to be affected after stimulation for half the duration of stimulation (Rotenberg, Horvath, & Pascual, 2014). This is especially advantageous for sentence comprehension studies as it allows us greater control and choice over which time window during a process is facilitated/disrupted within a sentence.

The sections above summarise the role of the IPS in sentence comprehension, and the potential advantages of studying it via online TMS. The section that follows provides an outline of how the two are combined in the present thesis.

1.5. Thesis Outline

Investigations focusing on reversible, syntactically simple and complex sentences shed some light on the processes involved in sentence comprehension. In a nutshell, the results of behavioural, lesion/symptom mapping, neuroimaging, and neurostimulation studies have established that:

1. Semantically reversible sentences, particularly with non-canonical word orders (such as passives) are more difficult to process than their canonical counterparts (such as actives).
2. The IFG and IPS are crucial for correct interpretation of non-canonical sentences.
3. The IPS seems to be particularly important for the reanalysis of non-canonical sentences.

While the literature reported in the previous sections highlight the involvement of both the IFG and the IPS, we focus solely on the IPS in this thesis. We did for three main reasons: (i) As seen above, previous literature suggests that the IPS seems to be particularly involved in processing non-canonical sentences requiring reanalysis; (ii) Another study by our team (Beber, Capasso, Maffei, & Miceli, in preparation) has found that the region of interest in this thesis – the left posterior intraparietal sulcus (l-pIPS) – and damaged areas of the parietal region in patients with difficulties in thematic role reanalysis overlap almost entirely; (iii) Logistical constraints made it unfeasible to contrast the IPS and the IFG. Due to the stringent inclusion criteria, participants were chosen from a limited pool. As a result, contrasting the IFG and pIPS in such a small number of participants would have greatly affected the power of the experiments. On the other hand, stimulating the IFG and pIPS in different participant pools could have introduced other confounding variables such as variability in brain organisation between the participant groups. As an alternative both the regions could be stimulated in the same participants. However, such a paradigm would entail doubling the number of sessions, thereby making it a month-long experiment with four weekly sessions and risking high drop-out rates.

However, these studies do not clarify the mechanisms that trigger reanalysis, and the role of the IPS in it. The current thesis reports an attempt at understanding the role of the pIPS in sentence comprehension, while considering the three factors that may induce reanalysis – reversibility, voice, and syntactic structure. The three experiments reported in this thesis follow up on the findings by Finocchiaro et al (2015) and Finocchiaro et al (submitted). In all cases, rTMS was administered to the l-pIPS, in order to understand the role of this region in sentence comprehension. The first experiment was conducted on native Italian speakers. Participants were presented with active/passive reversible and irreversible sentences in an agent/theme judgment task. The goal of this experiment was to establish whether reversibility is indeed a critical dimension in the comprehension of declarative reversible sentences. The second experiment was conducted on native speakers of Hindi (a language with a preferred SOV word-order). Its goal was to disentangle whether effects on passives are due to voice or non-canonical word-order. The experiment used reversible, syntactically simple active and passive voice sentences. The third and final experiment was conducted on native Italian speakers, in order to establish whether the effects of rTMS on declarative sentences were due to syntactic structure or to reversibility *per se*. Declarative active/passive voice sentences and majority/minority comparative sentences were presented in the context of a sentence-picture verification task. The three experiments are discussed in chapters 2, 3, and 4 respectively.

Chapter 2
The role of the l-IPS in the comprehension of reversible and irreversible sentences: an rTMS study[1]

Thematic roles can be seen as semantic labels assigned to who/what is taking part in the event denoted by a verb. Encoding thematic relations relies on both syntactic and semantic aspects and is crucial for sentence interpretation. In previous studies, repetitive transcranial magnetic stimulation (rTMS) over the left posterior third of the inferior intraparietal sulcus (l-pIPS) selectively influenced performance accuracy on reversible passive (but, not active) sentences. The effect was attributed to the fact that in these sentences the assignment of the agent and theme roles requires reanalysis of the first-pass sentence parsing.

To evaluate the role of reversibility and passive voice on the effect, rTMS was applied over l-pIPS during a sentence comprehension task that included reversible and irreversible, active and passive sentences. Participants were asked to identify who was performing the action or who/what the action was being performed on.

Stimulation of the l-pIPS increased response time on reversible passive sentences but not on reversible active sentences. Importantly, no effect was found on irreversible sentences, irrespective of sentence diathesis.

Results suggest that neither reversibility nor sentence diathesis alone are responsible for the effect. Instead, reanalysis is likely to be triggered/constrained by a combination of semantic reversibility and passive voice. Combined with the results of previous studies, and irrespective of the specific role of each feature, these findings support the view that the l-pIPS is critically involved in the assignment of thematic roles in reversible sentences.

[1] A modified version of this chapter has been submitted as Vercesi L., Sabnis P., Finocchiaro C., Cattaneo L., Tonolli E., & Miceli G. The role of the l-IPS in the comprehension of reversible and irreversible sentences: an rTMS study to *Neuropsychologia*.

2.1. Introduction

2.1.1. Thematic role assignment and sentence comprehension

In sentence comprehension different cues contribute to meaning interpretation. Among these, thematic roles (known also as *theta*-roles or case roles) are of particular interest. They can be seen as semantic labels assigned to who/what is taking part in the event described by the verb. In order to understand a sentence like *The girl sees the tree*, the listener must establish that *the girl* is the one who is doing the action (the agent), whereas *the tree* is what the action is being performed on (the patient/theme). The correct assignment of thematic roles relies on the combination of syntactic and semantic features, which makes this process an ideal case for investigating the mechanisms underlying sentence comprehension.

Word-order is an important syntactic dimension in sentence comprehension. In an subject-verb-object (SVO) language like Italian, words usually appear in canonical order in active sentences (agent-verb-theme), and in non-canonical order in passive sentences (theme-verb-agent). Therefore, interpretation of passives is more demanding. Sentence comprehension is also modulated by semantic reversibility. In irreversible sentences, only one constituent can be the agent. In the active sentence *The girl watches the tree*, word-order and semantic irreversibility greatly facilitate thematic role assignment. In the corresponding passive sentence *The tree is watched by the girl*, non-canonical word-order makes role assignment less easy. Still, in both cases agent and theme roles can be assigned based solely on semantic knowledge. In semantically reversible sentences, however, both constituents can be agent or theme. Therefore, comprehension requires syntactic processing. In active sentences (*The girl kisses the boy*) canonical word order facilitates thematic role assignment. In passive sentences (*The boy is kissed by the girl*); however, word order is non-canonical and semantic knowledge cannot constrain thematic role assignment. Due to non-canonical word order and semantic reversibility, these sentences must be reanalysed, and thematic roles reassigned (Chomsky, 1965; 1981; Pollard & Sag, 1994; Bresnan, 2000; Finocchiaro et al., 2015).

2.1.2. The neural basis of thematic role assignment

The neuroanatomical bases of sentence comprehension – particularly of passive and semantically reversible sentences – have been investigated in several studies, focusing on both normal and clinical populations and involving different techniques (lesion studies via Voxel-based Lesion Symptom Mapping (VLSM), fMRI studies and TMS studies). (For a recent review on neuroimaging data see Walenski Europa, Caplan, & Thompson et al., 2019).

Historically, the neural mechanisms underlying the comprehension of reversible sentences were first investigated in lesion studies on aphasic patients (see for example Caramazza & Zurif, 1976; Caplan & Futter, 1986; Grodzinsky, 2000; Love, Swinney, Walenski, & Zurif, 2008; Thompson & Choy, 2009). The inability to comprehend and produce sentences as a consequence of the inability to map thematic roles onto syntactic roles and vice versa was reported in two aphasic patients suffering from damage to left parieto-temporal regions (Caramazza & Miceli, 1991; Martin & Blossom-Stach, 1986). These early, almost anecdotal observations have been subsequently replicated by several investigations. Thothathiri, Kimberg, & Schwartz (2012) used VLSM (Bates, Wilson, Saygin, Dick, & Knight, 2003) in a large group (n=79) of aphasic patients. They found a significant correlation between poor comprehension of reversible sentences and damage to the left temporo-parietal cortex, but not to Broca's area. These results are consistent with other VLSM studies (see Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004 or Bates et al., 2003) and with an investigation of lesion extent/PET metabolism in parieto-temporal areas in patients with aphasia, which found a correlation between these regions and syntactic comprehension (Caplan et al., 2007). Evidence from these studies is consistent with the hypothesis that parieto-temporal areas play a role in the comprehension of reversible sentences. These regions could be involved in thematic labelling in non-canonical sentences, such as passive declaratives. Related results were reported by Rogalsky, LaCroix, Chen, & Anderson (2018), who studied the comprehension of canonical and non-canonical sentences in patients with chronic focal cerebral damage through a VLSM approach. They found maximal overlap in posterior superior temporal and inferior parietal regions.

Similar results were found in neuroimaging investigations on cognitively unimpaired participants (for reviews see Meyer & Friederici, 2015; Rodd et al., 2015; Martin et al., 2015; Walenski et al., 2019). For instance, an fMRI study by Richardson, Thomas, & Price (2010) evaluated the impact of semantic reversibility on the comprehension of semantically reversible sentences, over a range of syntactic structures. The contrast between reversible and irreversible sentences showed activation in a lateral portion of the left posterior-superior temporal gyrus and in an inferior parietal region. Activation during the processing of syntactic and semantic information was observed in anterior and posterior portions of the left middle temporal gyrus, in response to both reversible and irreversible sentences.

Neuromodulation studies provide additional evidence for the role of parietal regions in the comprehension of reversible sentences. Finocchiaro et al (2015) delivered transcranial magnetic stimulation (rTMS) to three sites along the l-IPS, in order to investigate their contribution to thematic role assignment during a sentence comprehension task. Experimental stimuli consisted of active and passive, semantically reversible sentences. In agreement with predictions, rTMS to the posterior l-IPS (l-pIPS) site increased performance accuracy on reversible passives (but not on actives). Another study by Finocchiaro, Cattaneo, and Miceli (submitted) that stimulated the l-pIPS replicated the effects on passive sentences. In addition, they also found an effect on 'passive' pseudosetences.

2.1.3. Experiment and hypotheses

The results from Finocchiaro et al. converge with available data in supporting the idea that parietal regions are critical for the comprehension of reversible sentences. However, experimental stimuli only included reversible sentences. This leaves the mechanisms underlying the observed effect unclear. Thematic reanalysis is required for sentences in which no reliable syntactic (word order) or semantic (reversibility) cues are available to constrain thematic role assignment, such as reversible passives. In these sentences, however, reanalysis could be triggered and/or constrained by several features of the stimulus. To establish whether passive diathesis, semantic reversibility, or both are involved in reanalysis, and to analyse in greater detail the role of l-pIPS in sentence comprehension, reversible and irreversible, active and passive stimuli were included in the present rTMS study.

During a sentence comprehension task, focal rTMS was delivered online to the l-pIPS – the same region that, when stimulated, affected performance accuracy in processing reversible passive sentences in Finocchiaro et al. (2015; submitted). Stimuli were organized in a 2x2 design: sentences could be either active or passive, and reversible or irreversible. We wished to understand whether the effect is due to passive diathesis or semantic reversibility *per se*, or to a combination of the two. If the effect were driven by reversibility, both active and passive reversibles should be affected by rTMS; on the contrary, if diathesis *per se* were relevant, the effect should involve passive sentences regardless of semantic reversibility.

2.2. Methods

2.2.1. Materials

A sample of 136 sentences was prepared. Of these sentences, 120 were used as experimental stimuli; the remaining 16 served as practice items. The following procedure was used in stimulus preparation.

A preliminary set of sentences was created. Sentences included common nouns (e.g. *architetto* (architect), *bambina* (girl)); and common verbs (e.g., *colpire* (hit)) that could be used in both reversible and irreversible sentences. Word frequency was controlled based on an Italian corpus (Bertinetto et al., 2005). Raw frequency values were used to obtain log frequencies before finalizing the list, in order to exclude extremely frequent or infrequent verbs/nouns.

Each selected verb was then paired with two sets of two nouns - in one set both nouns were animate, in the other a noun was animate and the other inanimate. As a result of these pairings, each verb was used in both reversible and irreversible sentences. The final list included 32 verbs, 30 of which were used for the main experiment. The remaining 2 verbs were included in the sentences used in the training procedure. Two verbs from the main list were used also in practice items, paired with different nouns.

As a result of this procedure, four types of sentences were created: reversible active sentences (RA), reversible passive sentences (RP), irreversible active sentences (IA), and irreversible passive sentences (IP). Examples of these sentence types can be seen in Table 2.1.

Table 2.1: *Examples of the sentence types included in the experiment*

Sentence Type	Example
Reversible Active Sentences (RA)	*La cameriera ha trovato la bambina* (The maid found the girl)
Reversible Passive Sentences (RP)	*La bambina è stata trovata dalla cameriera* (The girl was found by the maid)
Irreversible Active Sentences (IA)	*La cameriera ha trovato la borsa* (The maid found the purse)
Irreversible Passive Sentences (IP)	*La borsa è stata trovata dalla cameriera* (The purse was found by the maid).

2.2.2. Participants

Twenty-four healthy, right-handed, native Italian speakers were tested (f=15, m=9; mean age=24,70, SD=2,34). All participants had unimpaired or corrected-to-normal vision, and had no prior history of neurological conditions, seizures, psychiatric symptoms. For each participant, a structural MRI was used to accurately identify the area that would be targeted by rTMS stimulation.

In order to establish eligibility for the rTMS study, each participant completed a safety questionnaire. All participants read and signed a consent to participate in the experiment. The testing protocol was authorized by the Ethical Committee of the University of Trento.

2.2.3. Procedure

Participants took part in two experimental sessions, spaced apart by one week. Overall, the experiment required ~ 1 hour per participant. During the experiment, participants were seated in front of a computer screen. Six blocks with identical structure were created. Two served as practice, the remaining four as experimental blocks. At the beginning of each block, participants would see the question "who is performing the action?", thereby asking the participant to identify the agent or "who is the action being performed on?" thereby asking the participant to identify the theme. Each question was presented in alternate blocks. Participants were then asked to read a sentence presented at the centre of the screen and to answer the question presented at the beginning of each block by pressing one of two keys on the computer keyboard (2-alternative, forced choice task). In other words, participants were asked to identify the agent in one half of the blocks, the theme in the other half. Task demands were diversified across blocks, in order to reduce the likelihood that participants developed a systematic strategy. For example, if all blocks had been of the 'identify-the-agent' type, the correct response could have been produced by systematically looking at the constituent on the left (with actives: "***The girl*** *eats the apple"*) or on the right (with passives: "*The apple is eaten by* ***the girl***") of the verb. Blocks were counterbalanced so that two 'agent' or two 'theme' blocks were not presented consecutively. The same stimuli were presented in the real and sham conditions. The experiment was run on the E-Prime software. Accuracy and RT measures were collected.

Four experimental blocks were prepared, each containing 30 sentences. Half of the sentences in each block were active, the other half were passive. Each block had the following structure:

30 sentences:

- 15 active sentences (alternately 7 or 8 reversible)

- 15 passive sentences (alternately 7 or 8 irreversible)

Trials in each block were randomized and counterbalanced across participants. As mentioned above, participants had a fixed response window of 3000ms.

All responses were standardised by converting RT scores into *z scores* to better take account of outliers. For performance accuracy, responses that exceeded the fixed temporal window were excluded from the analyses.

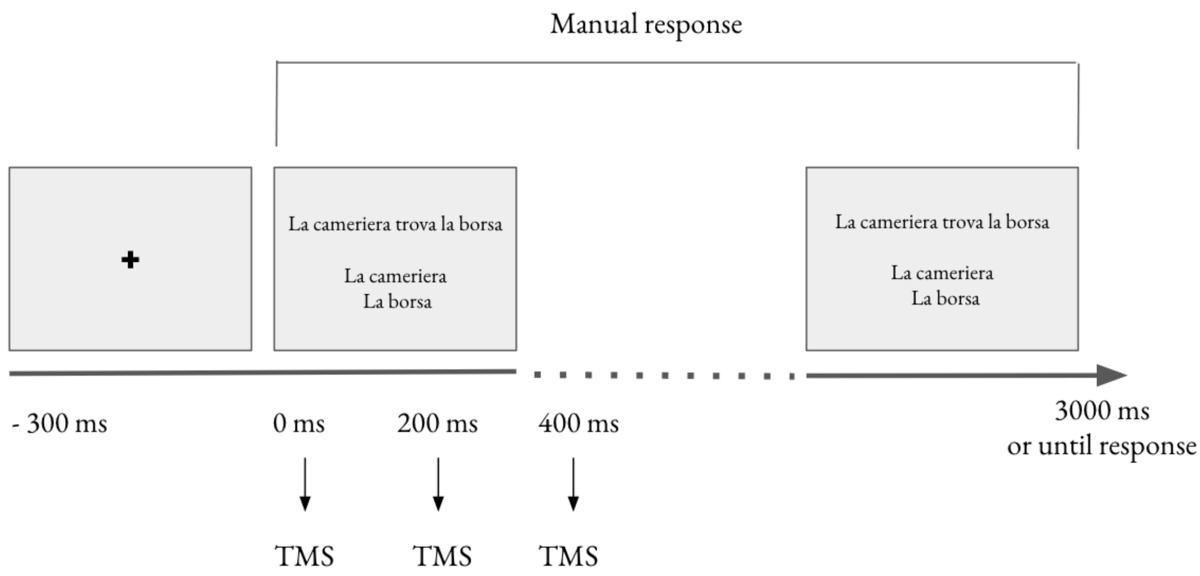

Figure 2.1: *Timeline of the experiment.*

2.2.4. Pre-Processing of RT Data

A within-participant design was adopted, so that each participant took part in both a sham and a real stimulation session. Preliminary analyses suggested that participants could have "learned" across sessions, as response times (RTs) were faster in the second session as compared to the first, irrespective of session type – real vs sham stimulation. Differently to RTs, performance accuracy did not improve across sessions. The practice effect on RT was consistent across participants and experimental conditions, suggesting that the amount of "learning" was constant and unrelated to specific experimental conditions. In order to quantify and cancel out this effect, the following procedure was used.

Firstly, the amount of "learning" was estimated in each subject by subtracting for each trial the RTs of the first session from those of the second session (which was associated with faster responses). The difference score thus obtained was individually applied to all experimental trials. Subsequently, the mean of this *delta* was calculated, yielding a constant value that was subtracted from each trial of the first session to cancel out the "learning" effect. This strategy allowed us to calculate corrected RTs for the first session, that could be compared to the second session while keeping account of the "learning" effect. RT scores were then standardised, and a natural logarithm transform was applied. Statistical analyses contrasted sham-TMS vs real-TMS sessions (i.e. independent of session order) for each experimental condition.

Individual RTs were corrected instead of using session as a covariate in the current analysis to ensure more precise corrections. Even though the second session was consistently faster than the first, regardless of TMS or sham stimulation, participants exhibited individual differences in terms of the amount of learning. Additionally, the amount of learning differed between the sentence types. Therefore, individual corrections were used to account for these differences.

2.2.5. TMS Protocol

The experiment was run in two conditions: real-TMS and sham-TMS. Each participant completed both conditions. The order of sessions (sham, then real vs real, then sham) was counterbalanced across participants. Participants received three biphasic pulses at 5 Hz starting from stimuli onset via a MC-B70 butterfly coil and a MagPro Compact stimulator (MagVenture). The sham-TMS was administered by inserting a spacer between the TMS coil and the scalp. Before starting the experiment, the individual visible resting motor threshold (RMT) was calculated as the lowest stimulation intensity applied over the primary motor cortex which produces more than five visible twitches of the right hand out of 10 stimuli. Stimulation intensity during the experiment was set at 90% of the individual visible resting motor threshold. The stimulator was triggered by the E-Prime software through the parallel port. TMS was delivered in an event-related fashion, time-locked to the presentation of visual stimuli. The coil was placed perpendicular to the pIPS, at 90° to the midline, and was pointed medially during both TMS and sham conditions.

2.2.6. MRI CO-REGISTRATION AND 3D RECONSTRUCTION

A structural MRI of each participant was available for spatially accurate administration of TMS. Stimulation sites were identified on individual 3D brain reconstructions based on macroanatomical landmarks. Before each session, the participant's head, the TMS coil and the 3D reconstruction of brain and scalp from individual MRI images were co-registered in space by means of the Softaxic Neuronavigation system using a Polaris Spectra camera. Coil position was checked online via the Softaxic Neuronavigation system and was adjusted to the target location based on reconstructions of individual brain anatomy. To locate the spot to be stimulated, the IPS was first identified, and its length divided in 3 segments. Subsequently, the midpoint of the most posterior segment was marked as TMS target (Figure 2.2 shows the anatomy and target points for all subjects).

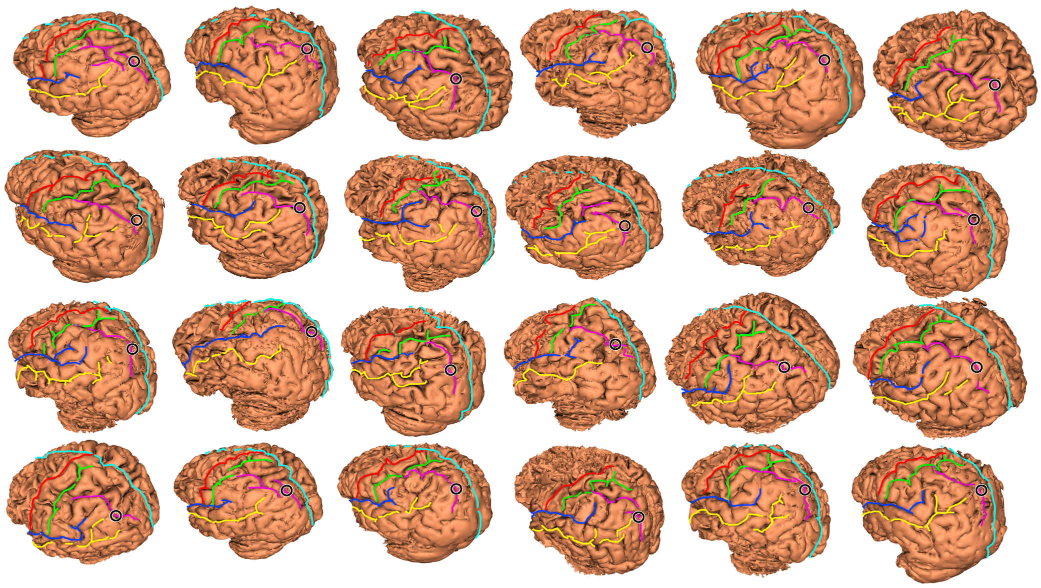

Figure 2.2: *Anatomy and target points for all subjects (n=24)*

2.3. Results

2.3.1. Reaction Times

Statistical analyses were run on the sham vs TMS contrast for each experimental condition (irreversible active (IA), irreversible passive (IP), reversible active (RA) and reversible passive (RP)). 148 of 2880 trials (5.13%) from the Sham condition, and 90 of 2880 trials (3.12%) from the TMS condition were excluded from the analysis.

Table 2.2 compares descriptive statistics for the sham vs TMS contrast in all experimental conditions.

Table 2.2: Showing standardised mean RTs and SDs for all four sentence types.

		Sentence Type			
		Irreversible Active (IA)	**Irreversible Passive (IP)**	**Reversible Active (RA)**	**Reversible Passive (RP)**
Condition	**Sham**	-0.27 (0.15)	0.02 (0.12)	0.005 (0.16)	0.15 (0.15)
	TMS	-0.28 (0.24)	-0.024 (0.16)	-0.27 (0.17)	0.24 (0.26)

The experiment followed a 2x2x2 design: *Stimulation* (Real vs. Sham); *Diathesis* (Active vs. Passive); *Reversibility* (Reversible vs. Irreversible). Since we adopted a within-participant design, data were analysed through a 3-way repeated-measures ANOVA with *DIATHESIS* (2 levels: *active* vs *passive*), *REVERSIBILITY* (2 levels: *irreversible* vs *reversible*) and *STIMULATION TYPE* (2 levels: *sham* vs *TMS*) as within-subject factors. (Fig. 2.3).

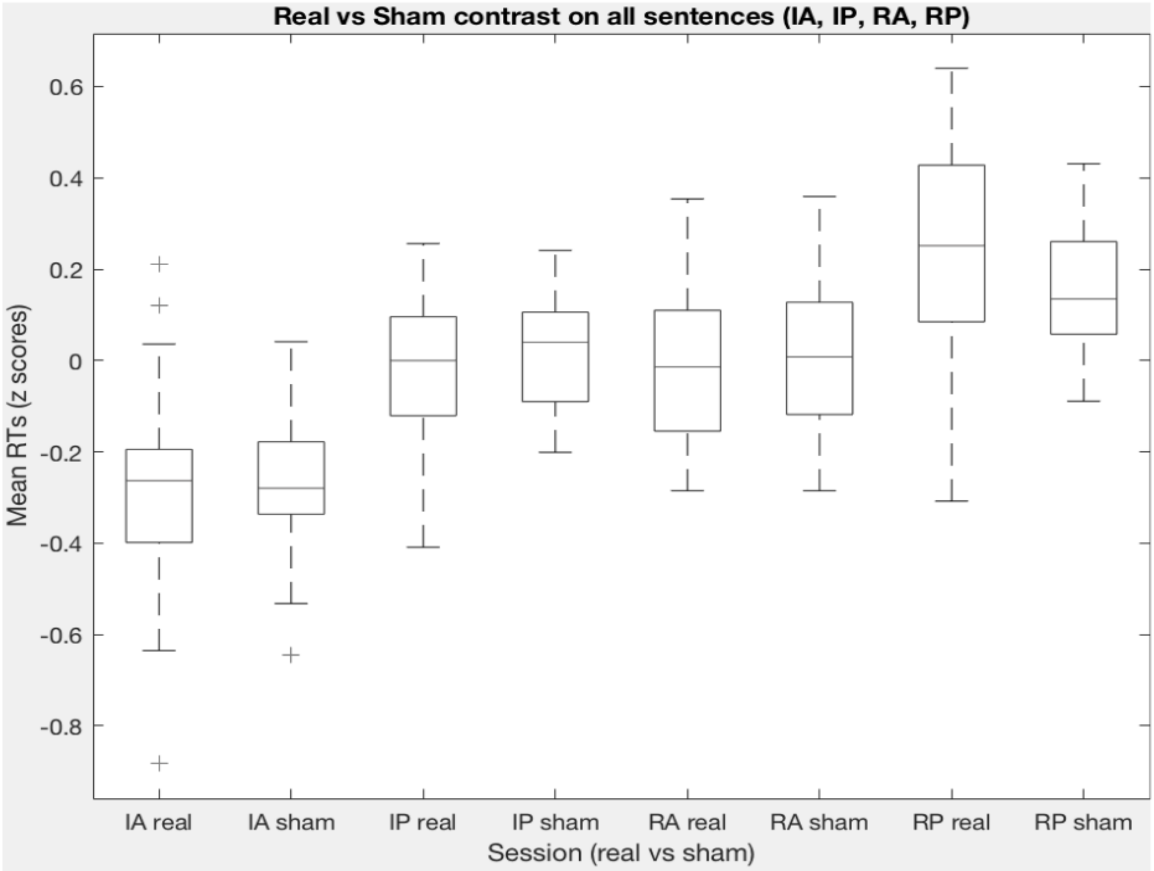

Figure 2.3: *Boxplot of RTs in the Real vs Sham contrast for all experimental conditions (irreversible active (IA), irreversible passive (IP), reversible active (RA) and reversible passive (RP)).*

The results on latencies show a main effect of *DIATHESIS* ($F(1,23)=43.190, p<0.001$) and of *REVERSIBILITY* ($F(1,23)=28.377$, $p<0.001$). No main effect of *STIMULATION TYPE* ($F(1,23)=0.007, p=0.934$) was found. No significant 2-way interaction effects were found on any of the comparisons (*DIATHESIS* x *REVERSIBILITY* ($F(1,23)=2.391$, $p=0.136$), *DIATHESIS* x *STIMULATION TYPE* ($F(1,23)=0.720$, $p=0.450$) and *REVERSIBILITY* x *STIMULATION TYPE* ($F(1,23)=1.642, p=0.213$).

Importantly, results show a significant 3-way interaction (*DIATHESIS* x *REVERSIBILITY* x *STIMULATION TYPE*) ($F(1,23)=5.825, p=0.024$). Bonferroni's post-hoc tests were then performed to account for this effect and further specify it. (Fig. 2.4). rTMS significantly increased RTs only on reversible passive sentences (RP) but not on reversible active sentences (RA) ($t=-8.205, p < 0.001$).

Stimulation did not influence response times on irreversible active and passive sentences (IA and IP) (*t*=0.043, *p*=0.966).

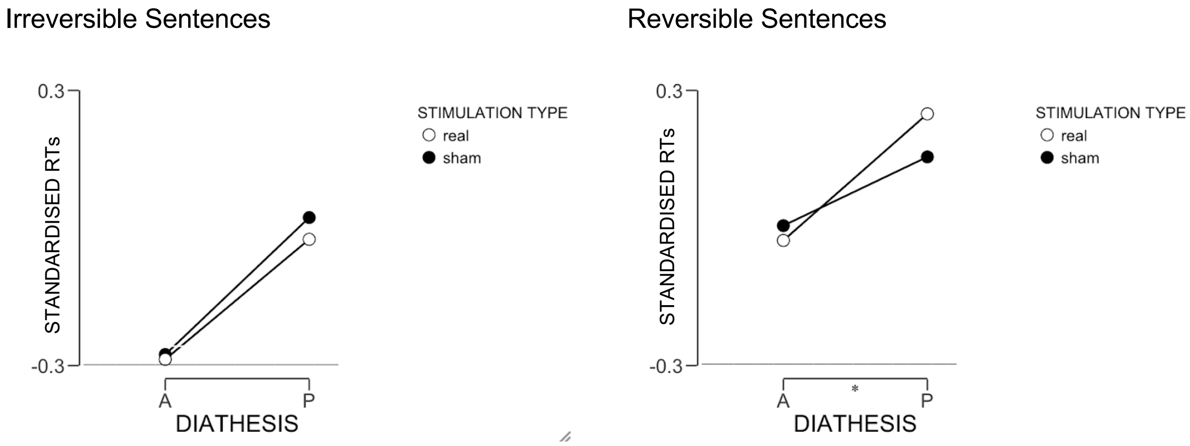

Figure 2.4: *Graph of Bonferroni's post-hoc tests for both active and passive reversible and irreversible sentences in the Real vs Sham contrast.*

Upon further investigation, it was seen that there were no differences between reversible active sentences in the two conditions the (*t*(23)=-0.82, p = 0.41). On the other hand, reversible passives were significantly slower in the TMS condition (*t*(23)=2, p = 0.05). It was also seen that reversible active sentences were significantly faster than reversible passive sentences within the TMS condition (*t*(23)=-5.03, p < 0.01) and the sham condition(*t*(23)=-3.55, p < 0.01).

2.3.2. Accuracy

Performance accuracy was analysed in the same way as RTs. The results show a main effect of *DIATHESIS (F*(1,23)=12.067, *p*=0.002) and of *REVERSIBILITY (F*(1,23)=43.782, *p*<0.001). No main effect of *STIMULATION TYPE* (*F*(1,23)=0.001, *p*=0.971) was found. No significant 2-way interaction effects were found on any of the comparisons (*DIATHESIS* x *REVERSIBILITY* (*F*(1,23)=0.115, *p*=0.634), *DIATHESIS* x *STIMULATION TYPE* (*F*(1,23)=0.233, *p*=0.161) and *REVERSIBILITY* x *STIMULATION TYPE* (*F*(1,23)=2.099, *p*=0.161*)*. More importantly no significant

3-way interaction (*DIATHESIS* x *REVERSIBILITY* x *STIMULATION TYPE*) ($F(1,23)=1.514$, $p=0.231$) was found (Fig. 2.5). Overall, stimulation did not affect performance accuracy in either experimental condition.

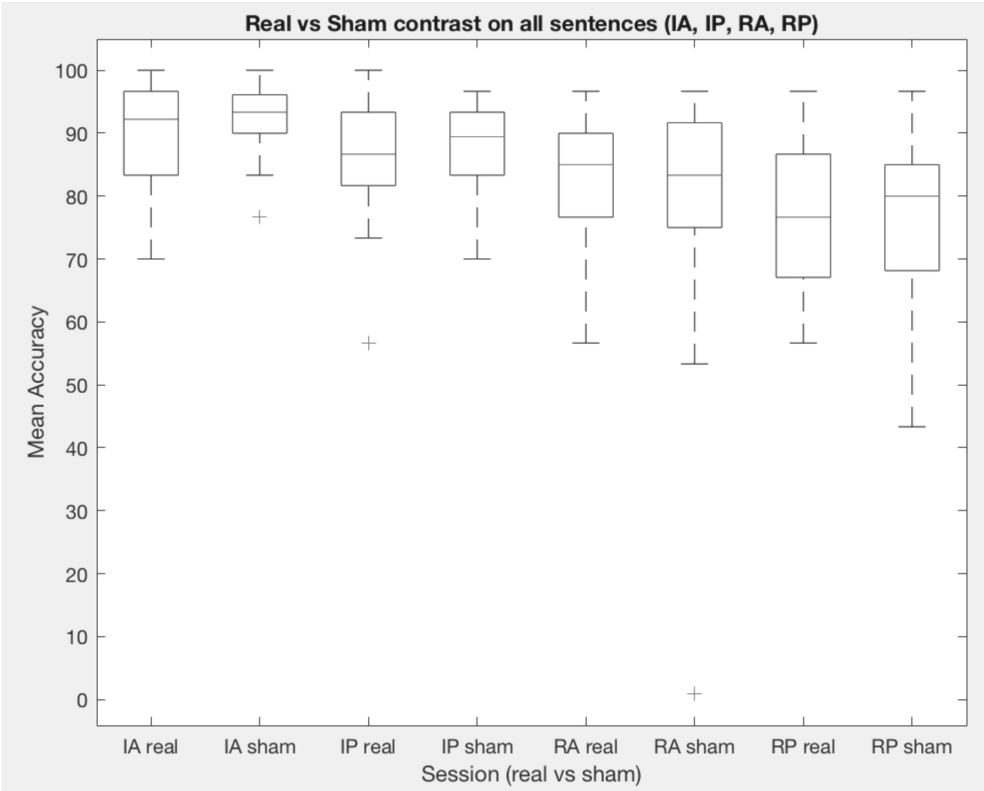

Figure 2.5: *Boxplot of performance accuracy in the Real vs Sham contrast for all experimental conditions (irreversible active (IA), irreversible passive (IP), reversible active (RA) and reversible passive (RP))*

2.4. Discussion

Functional neuroimaging and lesion studies show that parietal and temporal regions are critical for the comprehension of reversible sentences. Neuromodulation studies also show that reversible sentences in the passive diathesis behave differently to reversible active sentences. It is commonly assumed that this is because they require thematic reanalysis (i.e. the process through which previously assigned thematic roles are re-mapped because of non-canonical order and semantic reversibility (Chomsky, 1965; 1981; Pollard & Sag, 1994; Bresnan, 2000)). On this premise, we wished to understand which dimension of reversible passives is the most likely cause of their distinct behaviour and, consequently, what is the role of the l-IPS in subsuming the ‘distinctiveness’ of these sentences. We focused on two features of reversible passives that might account for their peculiarity: (i) passive diathesis and (ii) semantic reversibility. Both features have been shown to modulate sentence comprehension and meaning interpretation (Brookshire and Nicholas, 1980; Ferreira, 2003; Meyer et al., 2012; and the other studies cited in ‘Introduction’), but their relative weight is uncertain. In our experiment rTMS was selectively delivered to the posterior portion of l-pIPS while participants were engaged in a sentence comprehension task that required thematic role assignment in active and passive, reversible and irreversible sentences.

Reversible passive sentences behaved differently from the other sentence types used in this experiment. rTMS over the l-pIPS during the comprehension of simple declarative sentences increased response times only on reversible passives, while leaving the performance on active reversible sentences, and on active and passive irreversible sentences unaffected. This finding has clear implications. First of all, passive diathesis alone cannot account for the peculiar behaviour of reversible passives. If that were the case, rTMS should have influenced performance on all passives, irrespective of reversibility. The same conclusion can be drawn for semantic reversibility: if the effect were due to reversibility, rTMS should have affected only reversible sentences, regardless of whether they were active or passive. A more likely account of the behavioural results, then, is that only the interaction (or the co-occurrence) of passive voice and semantic reversibility triggers reanalysis of thematic role assignment and results in the observed, selective effect of rTMS on reversible passive sentences.

On this account, the l-pIPS would contribute to the comprehension of reversible sentences by providing the neural substrate needed to solve the computational problems posed by the lack of straightforward syntactic (canonical word-order) and semantic (reversibility) cues for sentence interpretation. This view is supported by evidence in the literature linking the l-pIPS to the comprehension of reversible and passive sentences (Keller, Carpenter, & Just, 2001, Wang et al., 2016; Mirman & Graziano, 2012; Wu, Waller, & Chatterjee, 2007; Finocchiaro et al., 2015; Finocchiaro et al., submitted; see also references in the Introduction). Several reasons for the involvement of l-pIPS can be offered.

The l-pIPS could be critical when assigning thematic roles in reversible passive sentences because it represents language-specific knowledge. It would implement both the knowledge necessary for thematic mapping and that needed for sentence voice processing. When comprehension requires integrating both types of linguistic knowledge, as in sentences that are both reversible and passive, the need for reanalysis pushes this area to a critical limit and makes it sensitive to rTMS. According to this view, the l-pIPS would play a strictly ‘linguistic’ role.

An alternative account is that the l-pIPS could be critical for the comprehension of reversible passives because it does represent linguistic knowledge, but also provides the neural substrate recruited by working memory resources. Reanalysis requires that information regarding the to-be-interpreted stimulus be maintained active while the first-pass parsing of the sentence is reviewed and/or revised. This account receives support from rTMS studies suggesting that the l-IPS provides the neural substrate of the storage component of working memory (Romero et al., 2006; Papagno et al., 2007, and Romero Lauro et al., 2010), and by neuroimaging studies suggesting that the l-IPS is part of a fronto-parietal network supporting verbal working memory functions (Henson et al., 2000; Baldo & Dronkers, 2006).

To some extent, these two accounts can be seen as complementary. The involvement of the l-pIPS in thematic role assignment and sentence comprehension could be related to its contribution to working memory processes. The l-IPS could play a domain-general role, by allowing the recruitment of working memory resources during cognitively demanding tasks. In this case, it would not sustain specifically linguistic demands, but would be recruited during complex working memory tasks associated to a high cognitive load. Alternatively, the l-IPS could play a role when the task requires to maintain active in working memory and manipulate linguistic features such as semantic reversibility and syntactic structure.

To sum up, results show that neither diathesis nor semantic reversibility *per se* account for the selective effects of rTMS on RTs to passive reversible sentences. The interaction or co-occurrence of these two features requires thematic role assignment to be reanalysed. This process is interfered with by rTMS, which yields the observed phenomenon. Results suggest that the l-IPS provides critical neural substrate for the successful completion of thematic role assignment under these cognitively demanding conditions. This could be because it is involved in phonological working memory processes (e.g., Lauro, Reis, Cohen, Cecchetto, & Papagno, 2010), because it is recruited by strictly linguistic phenomena independent of working memory demands, or for both reasons. This issue is particularly complex, as language comprehension requires the listener to activate not only information stored in long-term memory (such as semantic and syntactic knowledge), but also to maintain information on the to-be-comprehended sentence in working memory while further processes take place. Future studies should be directed at disentangling the two components.

2.5. Conclusions

This experiment complements previous findings showing that the posterior l-pIPS is involved in the comprehension of reversible passive sentences. We propose that this happens as a consequence of the need to review the assignment of thematic roles based on first-pass parsing. Results show that rTMS influenced RTs on reversible passive sentences but not on reversible active sentences, nor on irreversible active and passive sentences. Both in the present study and in previous investigations, rTMS influenced performance only on reversible passives. These results are consistent with the view that comprehending reversible passives requires reanalysing syntactic structure to reassign previously encoded thematic roles, as this process is influenced by an interaction/co-occurrence of diathesis and semantic reversibility.

Finocchiaro et al (2015) documented that rTMS to the posterior portion of the left posterior intraparietal sulcus (l-pIPS) affects the comprehension of passive reversible sentences. They attributed this result to the involvement of the l-pIPS in the reanalysis process that is thought to occur with passives. In a follow-up study, based on the observation that rTMS affected performance not only on passive sentences but also on 'passive' pseudosentences, Finocchiaro et al (submitted) suggested that reanalysis is triggered by reversibility, regardless of the semantic meaningfulness of a sentence. In keeping with these findings, the results reported in Chapter 2 also support the hypothesis that rTMS of left pIPS affects the processing of passive sentences because it interferes with the reanalysis process.

However, these results do not allow disentangling the specific aspects of reversible passive sentences that trigger the reanalysis. To better understand the role of voice and word-order in inducing reanalysis in passive sentences, I ran an experiment in Hindi, a subject-object-verb language. Hindi has a relatively free word-order that allows the agent and theme to appear in the preferred word-order (i.e., in the first and second noun position, respectively), in both active and passive sentences. The experiment is discussed in detail in Chapter 3.

Chapter 3

The role of the l-IPS in the processing of word-order

Recent repetitive transcranial magnetic stimulation (rTMS) studies focused on active and passive voice sentences (reversible and irreversible; real sentences and pseudosentences) support the hypothesis that the left posterior intraparietal sulcus (l-pIPS) is involved in the reanalysis of thematic role assignment in semantically reversible sentences. However, this could be for a number of reasons, as a number of features co-occur in passive sentences (and pseudosentences) in languages like Italian and English. Two such features are non-canonical word-order (the first argument is the theme, not the agent) and passive morphosyntax.

In an attempt to disentangle whether reanalysis is triggered by non-canonical word order or passive voice, the current rTMS experiment used Hindi active and passive sentences in a timed sentence-picture verification task.

Unlike the previous studies (conducted in Italian) that consistently showed an effect on reversible passive sentences, stimulation of the l-pIPS had no effect on Hindi actives or passives in the current experiment. Results suggest that passive voice and reversibility alone may not be sufficient to trigger reanalysis. Rather, reanalysis could be activated when passive voice is combined with other cognitively demanding features, like non-canonical word order.

3.1. Introduction

Sentence comprehension research has investigated various syntactic and semantic aspects of a sentence that aid in its correct interpretation. Much of this research has focused on semantically reversible and irreversible sentences with simple syntactic structures (e.g., Richardson, Thomas, & Price 2010). Typically, declarative reversible/irreversible sentences in the active voice and in the passive voice have been used. Studies (often in English) have consistently found that passive voice sentences are more difficult to comprehend than their active counterparts (e.g., Thothathiri, Kimberg, & Schwartz; 2012). Both reversible and irreversible passives require longer processing times and yield lower response accuracy than the corresponding active sentences (e.g., Thompson, Riley, Ouden, Meltzer-Asscher, and Lukic; 2013; Ferreira, 2003). Two main explanations are generally offered for this difficulty in the comprehension of passives – (i) non-canonical word order; and (ii) the frequency of usage of passive sentences compared to active sentences.

The derived order problem hypothesis (DOP-H; Bastiaanse & Van Zonneveld, 2005, 2006), an account of comprehension based on word order, assumes that every language has a base order (e.g., subject-verb-object (SVO) in English and Italian) and that all other word orders in that language are derived from it. The DOP-H postulates that all sentences with a derived order are more difficult to comprehend than sentences with the base order. However, some studies in Standard Indonesian challenge this account. An intriguing feature of this language is that, even though they are less frequent than actives, passive sentences are used rather frequently (28-35% in Indonesian, vs 4-5% in English) (Gil, 2006). A study by Anjarningsih, Haryadi-Soebadi, Gofir, & Bastiaanse (2012) on Standard Indonesian found that passive and active sentences were processed with comparable ease both by healthy volunteers and by patients with Broca's aphasia. These results contradict the predictions of the DOP-H, according to which passive sentences should be *per se* more difficult than actives. Based on these results, the authors suggested that syntactic structure alone could not account for comprehension deficits.

In a subsequent study on Indonesian, Jap, Martinez-Ferreiro, & Bastiaanse (2016) investigated the role of syntactic structure frequency in sentence comprehension. They compared performance on actives and passives and performance on subject-cleft and object-cleft sentences, which are less frequent and more complex. Non-brain-damaged participants showed ceiling effects for all sentence types. Participants with Broca's aphasia, on the other hand, demonstrated comparable performance on active and passive sentences. Accuracy was marginally but insignificantly lower on subject-cleft sentences, and significantly lower on object-cleft sentences.

By replicating the results of Anjarningsih et al (2012) on active and passive sentences, Jap et al reinforced the view that explanations relying solely on whether or not syntactic structures deviate from canonical word order cannot account for the differences observed in the comprehension of different sentence structures. On the other hand, based on the performance on cleft sentences (only object-clefts were significantly worse than declaratives), they also argued that the frequency of a syntactic structure, if considered in isolation from other dimensions, cannot account for the data. They reasoned that while the frequencies of a sentence construction and of the lexical items in a sentence play a crucial role in comprehension (Gahl & Menn, 2016), structure frequency alone cannot accommodate the observed effects of atypical thematic role assignment. For example, in English, subject-cleft constructions are less frequent than active sentences (see examples below), yet they are parsed with comparable ease (e.g., Abuom et al., 2013; Grodzinsky, 2000).

(1a) The boy hugs the girl. – Active

(1b) The girl is hugged by the boy. – Passive

(1c) It is the boy that hugs the girl. – Subject-cleft

(1d) It is the girl that the boy hugs. – Object-cleft

Similar results were seen on active sentences and subject-cleft sentences in Jap et al's study, in which an effect of word order was observed only with object-cleft sentences. Consequently, the authors suggested that both the frequency of a syntactic construction (along with the frequency of lexical items) and the word order in that syntactic construction are crucial for correct interpretation.

These studies bring to attention the importance of studying diverse languages with distinct properties for a better understanding of the mechanisms underlying sentence comprehension. In this study, I focus on Hindi, an Indo-European language mostly spoken in the northern part of India. Hindi is of particular interest in this context as it allows the same word order (agent-theme-verb) to be maintained in both active and passive voice sentences. This is discussed in more detail below.

3.1.1 Passive Voice in Hindi

Hindi is a relatively free word-order language with a preferred subject-object-verb (SOV) structure (Kachru, 2006). Unlike languages such as English and Italian, Hindi allows an agent-theme-verb order in both active and passive voice sentences (see Examples 2a and 2b).

2a) बच्ची(AGENT) नर्स(THEME) को छूती है। - Active

bachchi nars ko chhuutii hai

child nurse to touches

The child touches the nurse.

2b) बच्ची (AGENT) **द्वारा** नर्स (THEME)[SG.FEM] को छुआ[SG.M.PRS] जाता है। - Passive

bachchi dwaara nars ko chhuaa jaataa hai

child by nurse touched

The nurse is touched by the child.

Even though Hindi actives and passives may share word-order (as in sentences 2a and 2b), they still display a few major differences. Firstly, unlike actives, Hindi passives are marked by the postpositional phrase *(ke) dwaara* (के द्वारा) (by means of). Examples 2a and 2b illustrate this distinction (*(ke) dwaara* is highlighted in boldface). When the first argument in the sentence is a noun (as in sentence 2b), the *ke* in *(ke) dwaara* is optional[2]. In addition to the *(ke) dwaara* marker, Hindi actives and passives also include a case marker, the postposition *ko* (को), which follows the theme in both sentence types (Montaut, 2018). The usage of *ko* is mandatory in actives, but optional in passives. When used in passives, it establishes the agent's action as intentional. For example, the absence of *ko* in Example 2c conveys that Shanti's (the theme of a sentence where the mention of the agent in the sentences is omitted) death was an accident, whereas Example 2d, which uses *ko,* conveys that her death was premeditated.

2c) शांति मारी गयी।

shanti maari gayi

shanti killed

shanti was killed.

2d) शांति को मारा गया।

shanti ***ko*** *mara gaya*

shanti killed

Shanti was killed (murdered).

Finally, Hindi actives and passives differ in terms of verb agreement. In the active voice, the verb agrees with the subject (see Example 2a). In the passive voice, verb agreement is governed by two rules: when the object is not followed by a postposition, the verb agrees with the object (see Example 2e); when the object is followed by a postposition (*ko* in the current context), the verb and

[2] The *ke* in the *(ke) dwaara* is obligatory in passive sentences beginning with a pronoun (e.g., उस**के द्वारा** नर्स को छुआ जाता है। (us**ke dwaara** nurse ko chhuaa jaata hai.)) in Hindi. For more details on passive sentences in Hindi, please see Appendix C on Page 127.

the auxiliary do not agree with either the subject or the object. Instead, the masculine, singular form is used for both the main verb and the auxiliary verb (see Example 2b) (Kachru, 1966).

2e) बच्ची द्वारा नर्स[SG.FEM] छुई[SG.FEM.PRS] जाती है।

bachchi dvaaraa nars chhuii jaatii hai

child by nurse touched

The nurse is touched by the child.

The studies mentioned in section 3.1 also bring attention to the fact that factors such as voice may also affect reanalysis.

3.1.2. Current Experiment and Hypotheses

In the current study, I focus on the role of word-order in comprehending reversible sentences – a critical feature that distinguishes actives from passives; and on the role of voice. In English (see example 1b) and Italian SVO passives words appear in a non-canonical order, as the theme appears before the agent. Comprehension of these sentences is thought to require reanalysis, i.e., the remapping of thematic roles.

Previous studies have implicated the left posterior intraparietal sulcus (henceforth l-pIPS) in this reanalysis process. Finocchiaro et al. (2015) administered reversible declarative sentences in the active and in the passive voice. Results showed that rTMS to the l-pIPS increased accuracy on passives but not on actives. Finocchiaro et al. (submitted) set out to replicate these results by evaluating the effects of TMS not only on active and passive reversible sentences, but also on 'active' and 'passive' pseudosentences constructed by combining pseudonouns and pseudoverbs with real grammatical markers (determiners, prepositions, noun and verb inflections). TMS affected performance on passive stimuli, as expected, not only with real sentences but also with 'passive' pseudosentences. This result was accounted for by assuming that, despite being comprised of pseudowords as predicates and arguments, pseudosentences might mimic proto-thematic relationships. In other words, one of the 'pseudonouns' might be recognized as agent-like, the other as theme/patient-like (Dowty, 1991). Consequently, the pseudosentence might be considered (and treated by participants) as 'reversible'. On this account, verb meaningfulness does not seem to be a strong constraining factor for reanalysis, whereas reversibility of thematic roles appears to be a more reliable triggering factor. In a follow-up rTMS study, Vercesi, Sabnis et al. (submitted; see Chapter 2) sought further evidence for this account by contrasting performance on reversible and irreversible declarative sentences, both in the active and in the passive voice. As expected, TMS affected performance on reversible passive sentences but not on irreversible passive sentences or reversible or irreversible active voice sentences.

Overall, these studies show that rTMS to the l-pIPS selectively affects passive reversible sentences. On the view that passives require reanalysis, data support the idea that l-pIPS provides critical neural substrate for this process. However, since passives share two non-canonical features (passive voice and word order), it is unclear whether one, the other, or both are the more effective trigger for reanalysis. This question cannot be answered by studies on English or Italian. Due to the linguistic properties of English (see example 1b) and Italian (see sentences in Finocchiaro et al., 2015 and submitted), reversible passives are characterised by both passive voice and noncanonical word order.

The current experiment follows up on these studies to try and tease apart the role of sentence voice and word order in sentence reanalysis. I capitalise on the property of Hindi that allows the agent and the theme to appear in preferred word order (first and second noun position, respectively), in both active and passive voice sentences. In other words, Hindi passives maintain the preferred order in terms of both grammatical roles (i.e., subject and object) and thematic roles (i.e., agent and theme).

If the reanalysis of reversible sentences is triggered by non-canonical word-order, as suggested by studies conducted in SVO languages (Italian, but also English, etc.), TMS should have no effect on either actives or passives (or similar effects on both) in Hindi, since both the active and the passive sentences used in the experiment have a preferred word-order. On the other hand, reanalysis of reversible sentences may also be triggered by voice. In this case TMS could be expected to affect performance on passives, despite word-order being maintained.

3.2. Methods

3.2.1. Participants

Sixteen native Hindi speakers (12 males; mean age: 26.93 years; range 21-32 years) participated in the study. All participants were right-handed, had normal or corrected-to normal vision and hearing, and no history of psychiatric or neurological conditions. All had received formal education in Hindi at least until the 10th grade. Participants were screened to ensure compatibility with TMS. Details regarding the aim of the study were revealed only at the end of the second session. The study was approved by the Macquarie University Human Research Ethics Committee and all participants provided informed consent.

3.2.2. Stimuli

Two lists, one of common animate nouns (e.g., किसान (*kisan*, farmer)), the other of two-argument verbs such as छूना (*choona*, to touch) were compiled. Nouns and verbs were combined so as to result in fully reversible sentences. Combinations that were obviously unidirectional (e.g., माँ बच्चे को नहलाती है, *The mother bathes the child*) were avoided. Compound verbs such as मदद करना (*madad karna*, to help)[3] were excluded from the list to keep sentence length as homogeneous as possible. Verbs that denote spatial relations such as भागना (*bhaagna*, 'to run') were excluded because studies suggest the involvement of right parietal regions in processing spatial representations

[3] Verbs such as 'मदद करना' (to help) are categorized as *sanyukt kriya* (compound verbs) in Hindi. In such cases, the auxiliary verb loses its primary meaning, and helps the main verb express its meaning more clearly.

(Amorpanth et al., 2010; Baumann & Mattingley, 2014). Only easily picturable words were included. Lemma frequencies for the Hindi words were obtained from the Leipzig Corpora Collection (Goldhahn, Eckart & Quasthoff, 2012). Each verb was paired with two nouns to form reversible active and passive voice sentences (henceforth simply referred to as Actives and Passives respectively). All sentences were illustrated, with each picture representing two characters – one as the agent, and the other as the theme of the sentence (as seen in Fig 3.1). Two versions of each sentence were created to form matched items (the sentence and the picture corresponded) and mismatched items (agent and theme in the picture and in the sentence were reversed, so that picture and sentence depicted opposite events), such that both nouns appeared in both agent and theme position (see Examples 3a – 3d and Fig 3.1). One version of each sentence was used in one session, the alternate version in the other. For example, sentence 3a was used in the first session and sentence 3b in the second. All sentences were approximately matched for length, but Passives were longer than Actives by two words. Both Actives and Passives use the marker *ko* immediately after the theme/patient. In passives, the perfective of the main verb was used with the present habitual form of the auxiliary verb *jana* to maintain the same tense across active and passive stimuli. Lastly, passive sentences used the postposition *(ke) dwara* instead of *se*[4]. A total of 108 sentences were prepared (54 active, 54 passives; half matched and half mismatched).

बच्ची (child) + नर्स (nurse) + छूना (to touch)

3a. Active (Matched) – बच्ची$_{\text{(AGENT)}}$ नर्स$_{\text{(THEME)}}$ को छूती है।

bachchi nars ko chhuutii hai

child nurse to touches

The child touches the nurse.

3b. Active (Mismatched) – नर्स$_{\text{(AGENT)}}$ बच्ची$_{\text{(THEME)}}$ को छूती है।

[4] The postposition *se* is often used in *bhavvachya* or impersonal voice, i.e., to describe the capability of the agent, and also to passivize intransitive verbs (Davison, 1982). *(Ke) haathon* on the other hand introduces extreme emphasis on the agent. Therefore, the postposition *(ke) dwara* was used to avoid the unintentional usage of an impersonal voice (with *se*) or extreme emphasis on the agent (with *ke haathon*).

nars bachchi ko chhuutii hai

nurse child touches

The nurse touches the child.

3c. Passive (Matched) – बच्ची (AGENT) द्वारा नर्स (THEME) को छुआ जाता है।

bachchi dvaaraa nars ko chhuaa jaataa hai

child by nurse touched

The nurse is touched by the child.

3d. Passive (Mismatched) – नर्स (AGENT) द्वारा बच्ची (THEME) को छुआ जाता है।

nars dvaaraa bachchi ko chhuaa jaataa hai

nurse by child touched

The child is touched by the nurse.

Figure 3.1: *Sample illustration of the stimuli. The drawing was presented with the matching sentences बच्ची नर्स को छूती है (The child touches the nurse) and बच्ची द्वारा नर्स को छुआ जाता है (The nurse is touched by the child); and with the mismatching sentences नर्स बच्ची को छूती है (The nurse touches the child) and नर्स द्वारा बच्ची को छुआ जाता है (The child is touched by the nurse).*

The preferred word order in both Actives and Passives, and the postposition द्वारा ('dwara') in the Passives might provide sufficient information to identify the agent. In such a case, participants would not need to read the entire stimulus sentence to answer correctly, as the first noun would always be the agent. To avoid this potential bias and ensure that participants read the entire sentence before responding, foil sentences with verbs semantically related to those represented in the picture were also included. This strategy was motivated by the fact that verbs in Hindi occupy the final position in the sentence. All foil sentences were mismatched with the picture (see figure 3.2 and examples 4a – 4d). Three verbs used in the main experimental stimuli were also used in foil sentences, but with different noun pairs.

Figure 3.2: *Sample illustration of the foil stimuli. The illustration shows a grandmother hugging her granddaughter. It was used exclusively with the semantic foil sentences दादी पोती को चूमती है(The grandmother kisses the granddaughter), पोती दादी को चूमती है(The granddaughter kisses the grandmother), दादी द्वारा पोती को चूमा जाता है (The granddaughter is kissed by the grandmother), and पोती द्वारा दादी को चूमा जाता है (The grandmother is kissed by the granddaughter). All the semantic foil sentences were mismatched to the corresponding picture.*

4a. Active Foil 1 – दादी पोती को चूमती है।

daadi potii ko choomti hai

grandmother granddaughter kisses

The grandmother kisses the granddaughter.

4b. Active Foil 2 – पोती दादी को चूमती है।

potii daadi ko choomti hai

granddaughter grandmother kisses

The granddaughter kisses the grandmother.

4c. Passive Foil 1 – दादी द्वारा पोती को चूमा जाता है।

daadi dvaaraa potii ko choomaa jaataa hai

grandmother by granddaughter kissed

The granddaughter is kissed by the grandmother.

4d. Passive Foil 2 – पोती द्वारा दादी को चूमा जाता है।

potii dvaaraa daadi ko choomaa jaataa hai granddaughter by grandmother kissed

The grandmother is kissed by the granddaughter.

3.2.3. Procedure

The experiment was split in two sessions – TMS and sham. The order of sessions was counterbalanced across participants. During each session participants performed a sentence-picture verification task administered using E-Prime. Throughout the task, an active or a passive sentence was presented on a screen simultaneously with a picture. Participants were required to decide if picture and sentence matched (see sentences 3a-3d for examples of matched and mismatched sentences). Participants were asked to respond with a button-press as quickly as possible. Stimuli remained on-screen for 3000 ms. A fixation cross appeared at the centre of the screen for 500 ms before every item (see Figure 3). Stimulus-onset asynchrony (SOA) was kept constant across participants. Response times (RTs) and response accuracy were recorded.

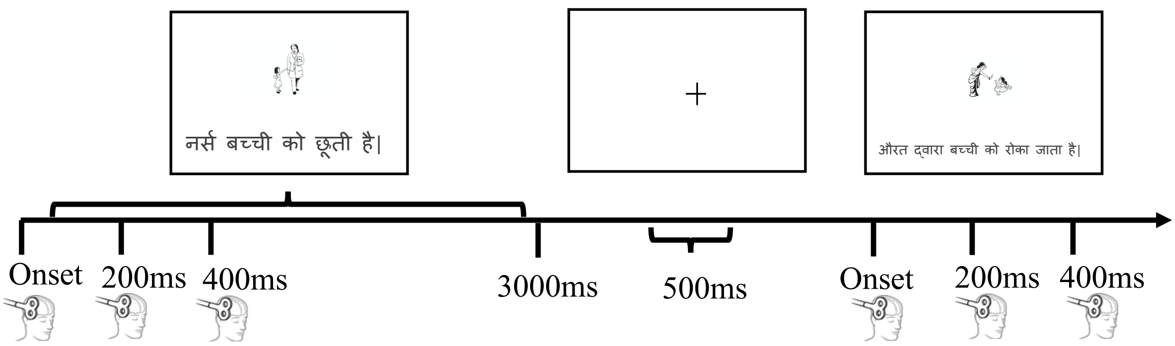

Figure 3.3: *Timeline of the experiment.*

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The experiment consisted of two practice blocks and three experimental blocks. Each block consisted of 8 Actives, 8 Passives, 4 Active Foils, and 4 Passive Foils. No verb was repeated within the same block. In each block, Actives and Passives (including foils) were presented in different random order. Equal numbers of matching and mismatching Actives and Passives were included. All foil sentences were mismatched. Alternate versions of the sentences were presented in the two sessions, so that the participant never saw the same sentence twice. Pictures were presented in different blocks in the two sessions, i.e., if a picture appeared in Blocks 1 and 2 in the first session, it would appear in Blocks 2 and 3 or Blocks 1 and 3 in the following session. Pictures were flipped horizontally in alternate blocks to prevent participants from using visual cues and strategies across blocks (e.g., the agent appeared on the left or on the right side of the picture an equal number of times).

Practice items were split into two blocks. The first, untimed block served to familiarise the participant with the task format; the second block was timed and served to familiarise the participant with the full experimental setup. The experiment in each session lasted approximately 15 minutes including mandatory breaks to reduce fatigue.

3.2.4. Stimulation Parameters

Biphasic pulses of 5Hz were applied to the l-pIPS at the onset of the stimulus, and at 200ms and 400ms from onset. Procurement of structural MRIs for individual participants was not possible. Therefore, the target site for stimulation was localized using the international 10/20 coordinates, similar to Finocchiaro et al (submitted). Based on the probabilistic maps of cortical structures underlying the international 10/20 coordinates (Herwig et al., 2003; Okamoto et al., 2004; Koessler et al., 2009; Kabdebon et al., 2014), the pIPS region of interest for this study most likely underlies the P1 coordinate (see Fig 3.4), which was therefore identified for each participant. Neuronavigation was used to monitor and minimise coil movement during the experiment.

Individual *visible* resting motor threshold (RMT) was established by stimulating the motor cortex in individual participants. This was considered to be the minimum stimulation intensity required to elicit a visible twitch of the right index finger in half of ten consecutive trials. TMS pulses were delivered via a figure-of-eight coil (Magstim Super Rapid, Magstim, Whitland, United

Kingdom). The coil was placed on the scalp such that the handle pointed medially, and was perpendicular to the pIPS, at 90° to the midline.

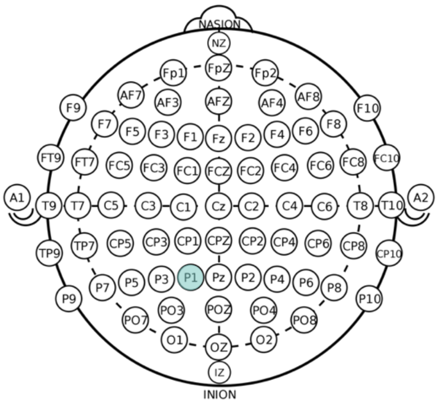


Figure 3.4: *The point of stimulation for participants according to the 10/20 coordinate system.*

During the experiment, participants were stimulated at 100% intensity of their visible RMT (mean = 69.11%, SD = 8.96 %). The stimulator was triggered using E-Prime via a parallel port.

3.2.5. Data Pre-processing and Analyses

Initial analyses indicated that RTs were consistently faster in the second session, regardless of stimulation type (TMS or sham) across both sentence types, suggesting a practice effect. Consistent patterns of change across sessions were not apparent in the accuracy analyses. This practice effect was corrected by subtracting the RTs of the second session from those of the first session for each trial in each participant. Subsequently, the mean value of this *delta* was calculated, and was added to each trial of the second session as a correction for the practice effect. All statistical analyses for RTs were run on these corrected scores. The preliminary analyses suggested that the learning effect between the two sessions while consistent, varied between participants. Corrections were made to individual RTs to account for the individual differences.

Accuracy percentages were converted to standardised scores using a natural logarithmic transformation. All accuracy analyses were conducted on these standardised scores. TMS and Sham conditions were then contrasted, independent of session order.

RT and accuracy were analysed using 3-way repeated measures ANOVA with the factors *STIMULATION* (TMS vs Sham), *SENTENCE TYPE* (Actives and Passives), and *CORRESPONDENCE* (Matched and Mismatched).

A *d'*-prime analysis was also conducted to evaluate differences in performance between matched and mismatched items. *d'*-prime values for Actives and Passives in the TMS and sham conditions were computed. After this, a 2-way repeated measures ANOVA with the factors *STIMULATION* (TMS vs Sham) and *SENTENCE TYPE* (Actives vs Passive) was used to analyse *d'*-prime values to check for differences in performance on matched and mismatched items between sentence types.

3.3. Results

RTs and accuracy on Active and Passive sentences in the TMS and sham conditions are summarised in Table 3.1, and figures 3.5 and 3.6. 86 of 768 trials (11.19%) were excluded from the analyses in the TMS condition and 89 of 768 trials (11.58%) were excluded in the Sham condition.

3.3.1 Reaction Times (RTs)

A 3-way repeated measure ANOVA was conducted on corrected RTs with the factors *STIMULATION TYPE* (TMS vs. Sham), *SENTENCE TYPE* (DA vs DP), and *CORRESPONDENCE* (Matched vs Mismatched). There was a main effect of Sentence Type ($F(1, 60) = 0.13$, $p = <0.01$), with Actives being responded to significantly faster than Passives sentences. Post-hoc analyses showed that the comparison between Actives and Passives sentences reached significance in both the sham and the TMS conditions ($t(15)= -2.2$, $p = 0.04$ and $t(15)= -2.49$, $p = 0.02$, respectively).
No main effect of *STIMULATION TYPE* ($F(1, 60) = 0.32$, p = 0.57) and *CORRESPONDENCE* ($F(1, 60) = 0.266$, p = 0.13) were observed. No interaction effects were found for *STIMULATION TYPE* *

SENTENCE TYPE ($F(1, 60) = 0.49$, p = 0.48), *CORRESPONDENCE * SENTENCE TYPE* ($F(1, 60) = 0.02$, p = 0.86), *STIMULATION TYPE * CORRESPONDENCE* ($F(1, 60) = 0.11$, p = 0.73), or *STIMULATION TYPE * SENTENCE TYPE * CORRESPONDENCE* ($F(1, 60) = 0.19$, p = 0.66).

Table 3.1a: *RTs and performance accuracy percentage (means and standard deviations) on Sentence Types across conditions*.

		Sentence Type			
		Actives RTs	**Passives RTs**	**Actives Accuracy**	**Passives Accuracy**
Condition	**Sham**	2119.76 (301.76)	2195.38 (265.83)	73.1 (4.44)	73.09 (4.44)
	TMS	2065.48 (257.36)	2177.45 (268.69)	70.39 (4.51)	74.59 (4.35)

Figure 3.5a: *Mean RTs on Actives and Passives within stimulation conditions*.

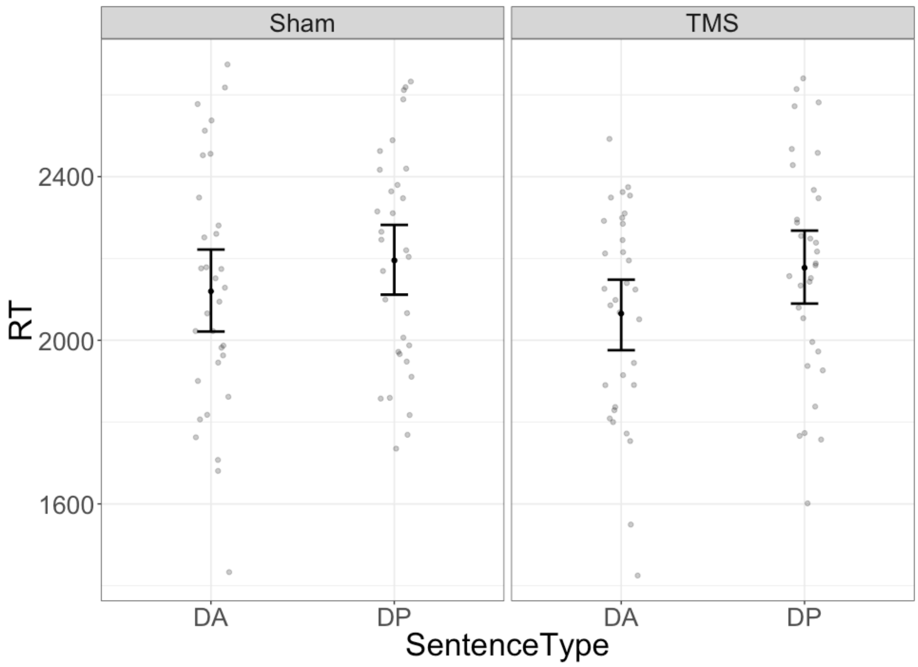
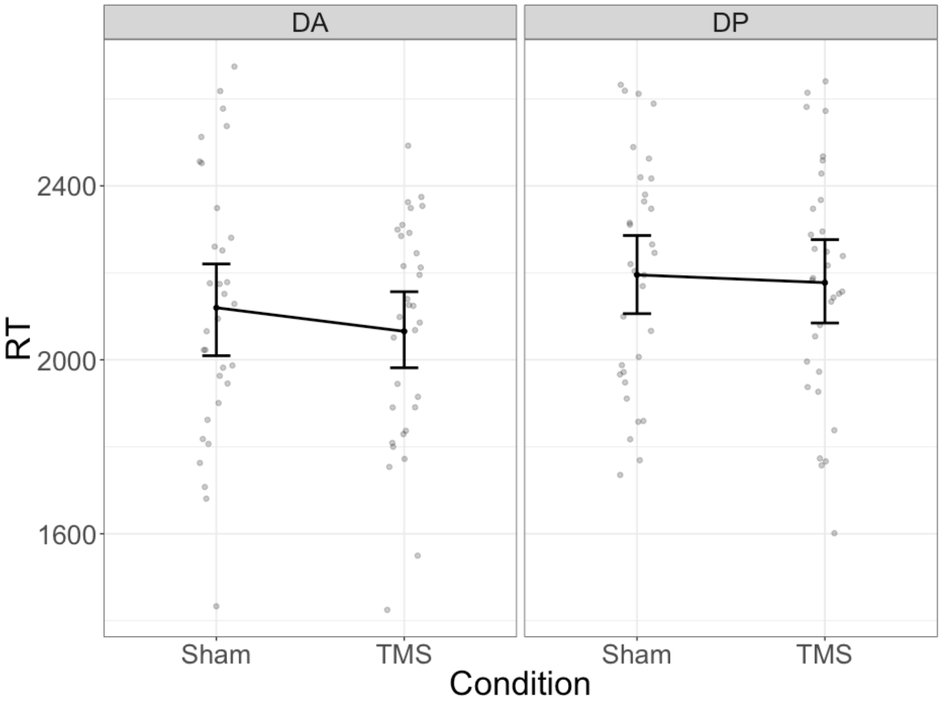


Figure 3.5b: *Mean RTs on Actives and Passives across stimulation conditions.*



3.3.2. Accuracy

A 3-way repeated measure ANOVA was also conducted on accuracy as a dependent measure with the factors *STIMULATION TYPE* (TMS vs. Sham), *SENTENCE TYPE* (DA vs DP), and *CORRESPONDENCE* (Matched vs Mismatched). There was a main effect of correspondence (*F*(1, 60) = 4.8, p = 0.03), i.e., accuracy was significantly higher for matching items than for mismatching items, but no main effect of *STIMULATION TYPE* (*F*(1, 60) = 0.05, p = 0.81) or *SENTENCE TYPE* (*F*(1, 60) = 2.2, p = 0.14). No interactions were found between *STIMULATION TYPE * SENTENCE TYPE F*(1, 60) = 0.95, p = 0.003), *CORRESPONDENCE * SENTENCE TYPE F*(1, 60) = 0.71, p = 0.4), *STIMULATION TYPE * CORRESPONDENCE F*(1, 60) = 0.0004, p = 0.99) were noted. No differences were noted between DA and DP sentences within conditions either.

Table 3.1b: *Showing mean performance accuracy and standard deviations in matched and mismatched items*.

		Sentence Type	
		Actives	**Passives**
Correspondence	**Matched**	86 (6.65)	72 (8.95)
	Mismatched	59 (12.57)	61 (5.99)

Figure 3.6a: *Accuracy on Actives and Passives within stimulation conditions*.

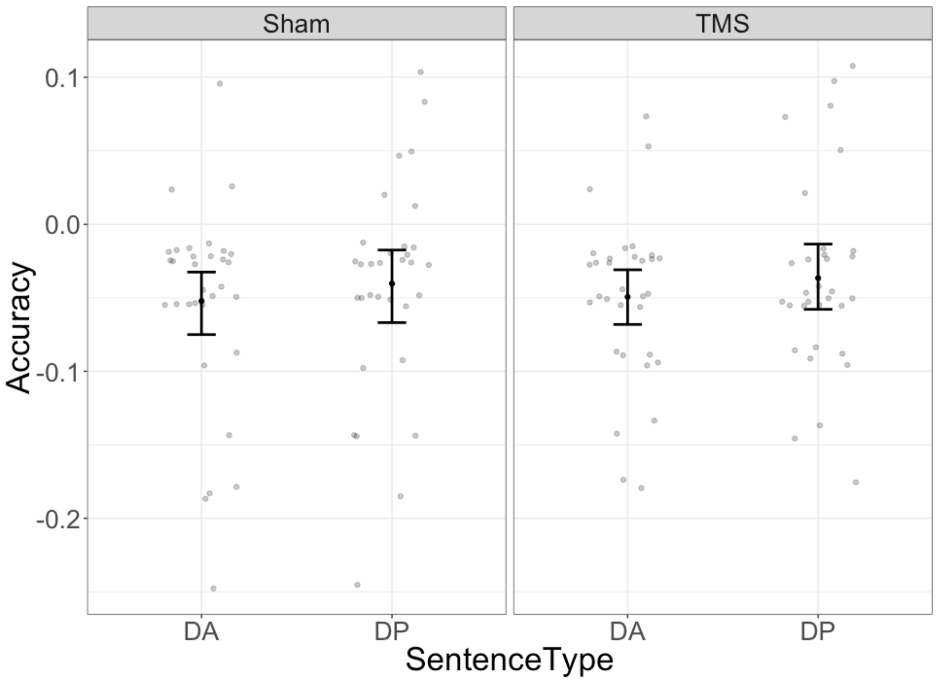
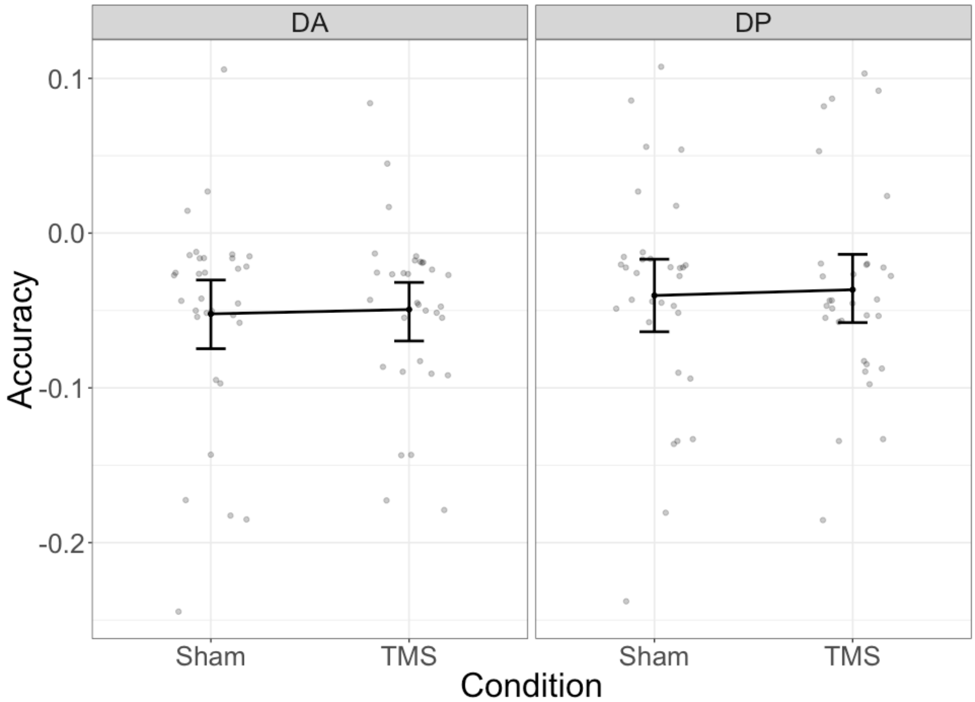


Figure 3.6b: *Accuracy on Actives and Passives across stimulation conditions.*



3.3.3. D-Prime

A *d'*-prime analysis was run on Actives and Passives using a 2-way repeated measures ANOVA with the factors *STIMULATION TYPE* (TMS vs. Sham), and *SENTENCE TYPE* (Actives vs. Passives). No main effects or interactions were noticed. These results align with the comparable figures for Actives and Passives seen in the accuracy ANOVA.

Table 3.2: *d' values for analysis excluding foil sentences.*

	Actives (without foil)	**Actives (with foil)**	**Passives (without foil)**	**Passives (with foil)**
Sham	1.32	1.13	1.43	1.28
TMS	1.29	1.19	1.43	1.40

3.4. Discussion

The current experiment had two main goals: i) to gain a better understanding of word-order and voice in inducing reanalysis; ii) to clarify the role of l-pIPS in such reanalysis. Assuming (based on previous literature) that the l-pIPS is involved in reanalysis it was hypothesised that, if non-canonical word order is a crucial trigger for this process, TMS to the l-pIPS would not affect either Actives or Passives. On the other hand, if voice alone suffices to induce reanalysis, rTMS should interfere with Passives, but not with Actives.

Results showed longer RTs for Passives as compared to Actives, regardless of stimulation type. This may have been due to different sentence length, or to the different structure frequency for Actives vs Passives. There were no differences in performance accuracy. Comparable difficulty for both sentence voices is further supported by the lack of differences between *d'* of the sentence types across conditions. As regards the aims of the experiment, no effects of TMS were found on either sentence type. These results may have been due to several reasons.

3.4.1. Postpositions and Morphosyntactic Features

Comparable accuracy on Actives and Passives may have been due to the rich morphosyntactic system of Hindi, that includes postpositions, a rich inflectional morphology and a rich auxiliary system. Unlike English, passivization of a sentence in Hindi is marked by postpositions and morphosyntactic changes.

For example, when the active English sentence '*the boy hit the girl*' is transformed into the passive voice '*the girl was hit by the boy*', (i) the past participle of '*hit*' must precede the verb, and '*by*' must precede the agent; (ii) the object of the active sentence (often with the thematic role of 'theme') is moved to the subject position of the passive sentence; (iii) the subject of the active sentence (typically playing the role of 'agent') is moved to the second argument position (Davison, 1982).

As noted in the Introduction, such reordering need not occur in Hindi passives. Hindi has a relatively free word-order with SOV as the preferred (but not obligatory) word-order (Kachru, 2006). Consequently, both SOV and OSV sentences like those shown in 5a and 5b are legal. Hindi passives are marked by the demotion of the agent noun phrase to an instrumental noun phrase. They also involve a change in verb morphology with the addition of the auxiliary verb *-jaa* at the end of the main verb which carries tense and aspect information (Davison, 1982).

5a. राम(SBJ) द्वारा रघु(OBJ) को देखा गया।

ram dvaaraa raghu ko dekhaa gayaa

ram by raghu seen

Raghu was seen by Ram.

5b. रघु(OBJ) को राम(SBJ) द्वारा देखा गया।

raghu ko ram dvaaraa dekhaa gayaa।

raghu ram by seen

Raghu was seen by Ram.

Both versions of the passives shown in 5a and 5b use the case-marking postposition *ko* to identify the object and the postposition *dwaara* to identify the subject. In combination, both these markers and verb morphology constrain the interpretation of Hindi passives. Previous studies have found that case markers facilitate sentence comprehension in many languages (MacWhinney et al., 1984, MacWhinney et al., 1985, Slobin & Bever, 1982, Smith & Bates, 1987). Therefore, the use of these markers and verb morphology should aid comprehension of both sentences 5a and 5b similarly. In sentences 5a and 5b, both grammatical and thematic roles are reversed. If these markers are more salient cues than word order, both types of sentences should be comprehended comparably. This was not true in a pilot experiment that was run before settling on the experiment described above. In the pilot, non-brain-damaged participants (N = 10) comprehended 5a as accurately as active sentences but scored at chance (mean accuracy: ~45%) on sentences like 5b. The performance on the pilot test could also indicate the influence of factors other than grammatical markers, of course. However, given random performance, it would have been impossible to disentangle the mechanisms responsible for the results. Therefore, these sentences were not used in the main experiment.

The Actives and Passives used in the current experiment also differ in terms of verb agreement. In Hindi passives, when the subject and the object are followed by a postposition, the verb agrees with neither and instead is used in its singular, masculine form (Kachru, 1966). While postpositions lengthen passive sentences, I speculate that the neutral verb agreement may not necessarily complicate sentence processing. An indication that this could be the case is seen in RTs and performance accuracy, where Passives have consistently longer RTs than Actives, but are comprehended with comparable accuracy.

3.4.2. Frequency and functionality of passives

Another factor that could explain comparable accuracy on Actives and Passives is the frequency of Passives in Hindi. Even though systematic studies identifying differences in structural usage are missing, some studies have noted that passive sentences are used more frequently in Hindi (~10%) (Bolgün & Mangla, 2017) than in English (4-5%) (Gil, 2006). In particular, Hindi passives are used to express politeness (Pandharipande, 1979; Srivatsa & Pandit, 1988), similar to the functional usage of passives in Standard Indonesian (see Randriamasimanana, 1999). Frequent exposure to Passives may have helped participants comprehend both Actives and Passives with similar ease.

3.4.3. General Discussion

In the current experiment, Hindi active and passive sentences (both following the preferred SOV word-order) were used. While Actives systematically resulted in shorter RTs than Passives, performance accuracy on both was comparable. More importantly, both Actives and Passives remained unaffected by TMS.

While exercising caution in interpreting the null results of the study, I posit that the comparable performance on Hindi Actives and Passives in real and sham TMS conditions is compatible with the idea that word order may be a stronger factor than voice in eliciting reanalysis. Had voice alone been a strong enough factor to engender reanalysis, an effect of rTMS on Passives should have been seen. The lack of these effects may be because both agent and theme appear in the preferred order in both stimuli (first noun = subject = agent, second noun = object = theme) and therefore the sentence may not warrant reanalysis. Consequently, the null results may also provide indirect, albeit weak, evidence for the role of the l-pIPS in reanalysis. These claims remain tentative until further experimental conditions are put to the test (like the OSV example used in the pilot).

Considerations on the frequency and the communicative role of passives, morphosyntactic changes, and the facilitative role of case markers in Hindi passives may partly account for the comparable performance accuracy on Actives and Passives. Consideration of the contrasting performance observed in the pilot study and in the final experimental paradigm suggests that while postpositions and case markers may serve as facilitative cues when interpreting frequently occurring syntactic structures, they may have a detrimental effect in the presence of structures with non-canonical word order. However, further experimentation is needed to better understand this issue.

3.5. Conclusion

Results are consistent with the view that word order in reversible sentences is a key factor in eliciting reanalysis, whereas voice alone, in the absence of a non-canonical word-order, is not critical with this respect. Null results must be taken with great caution, as the contrast between this experiment and the pilot study could also be interpreted as suggesting that reanalysis may be triggered by additional factors, such as the relative frequency of a syntactic structure. Further studies are needed to disentangle these questions.

Chapter 4

The role of the l-pIPS in processing reversibility

Several repetitive transcranial magnetic stimulation (rTMS) studies have shown that the posterior portion of the left intraparietal sulcus (l-pIPS) is involved in the processing of reversible sentences (and pseudosentences) in the passive voice. The effect of rTMS has been observed in experiments using only reversible sentences (Finocchiaro et al, 2015); real sentences and pseudosentences (Finocchiaro et al, submitted), reversible and irreversible sentences (Vercesi, Sabnis et al, submitted). However, studies so far have been unable to identify which factors may specifically trigger/influence reanalysis. The null result of rTMS on the processing of active and passive reversible sentences in Hindi, in which the same canonical word order is maintained in active and passive sentences) is compatible with the possibility that non-canonical word-order is a powerful trigger for the reanalysis of passives in languages like English and Italian but, like all null results, must be taken with caution. In brief, evidence from studies using active and passive reversible stimuli converges in attributing a relevant role in reanalysis to l-pIPS, but still does not clarify the mechanisms involved in reanalysis.

In this experiment, I used Italian declarative active and passive sentences along with comparatives of majority and minority in order to disentangle the role of word order and reversibility in reanalysis. Comparatives were selected because unlike Italian active and passive sentences, they can express reversible relationships while retaining an identical word-order and morphosyntactic structure. I attempted to identify the dimension(s) that elicit reanalysis by using rTMS on the l-pIPS during a sentence-picture verification task. Unlike in Finocchiaro et al (2015; submitted) and Vercesi, Sabnis et al (submitted), rTMS did not affect processing of passive sentences. However, it selectively reduced RTs to comparatives of majority. Results obtained from this paradigm suggest that reanalysis may refer not just to thematic reanalysis, but in general to the need to revise the first-pass parsing of a sentence. Such reanalysis may be triggered by reversibility, irrespective of word-order related issues.

4.1. Introduction

Sentences with varying syntactic structures are frequently used to understand how the brain processes various aspects necessary for the correct comprehension of a sentence, such as thematic role assignment, syntax, working memory, etc. Many such experiments exploit the properties of semantically reversible sentences, or a combination of semantically reversible and irreversible stimuli (e.g., behavioural studies: Kinno, Kii, Kurokawa, Owan, Kasai, & Ono, 2017; Wassenaar & Hagoort, 2007; Yano, Yasunaga, & Koizumi, 2017; lesion studies: Caramazza & Zurif, 1976; Caplan & Futter, 1986; Grodzinsky, 2000; neuroimaging studies: Thothathiri et al, 2012; Dronkers et al 2004).

In recent years, the neurofunctional correlates of sentence comprehension have also been studied by analysing the comprehension of reversible sentences during repetitive transcranial magnetic stimulation (rTMS). In a study with Italian healthy participants, Finocchiaro, Capasso, Cattaneo, Zuanazzi, & Miceli (2015) analysed performance on reversible sentences in both the active and the passive voice. The selective increase in accuracy on passive sentences, during rTMS of the posterior third of the left IPS (henceforth, l-pIPS) was attributed to the involvement of the l-pIPS in thematic role assignment. Finocchiaro et al. proposed that this region is critical for the reanalysis (i.e., reconsideration and revision of initially assigned thematic roles) required by reversible passive sentences. According to this view, the l-pIPS intervenes when the non-canonical order of the thematic roles in passive sentences needs to be reanalysed, in order to achieve the correct sentence interpretation.

In a follow-up rTMS study Finocchiaro, Cattaneo & Miceli (submitted) stimulated l-pIPS while participants read reversible sentences and pseudosentences (i.e., sentences comprised of pseudowords) presented in the active or in the passive voice. rTMS facilitated the comprehension of passive sentences, irrespective of whether they contained meaningful words or nonwords. These results are consistent with the view that l-pIPS is recruited when sentence interpretation requires reanalysis of temporarily encoded thematic roles (as in reversible passives), even in the absence of semantics. The presence of the effect also with passive pseudosentences was taken to indicate that the two pseudonouns were treated as 'proto-agent' and 'proto-theme', and that as such their relationship (expressed by a pseudoverb), being semantically unconstrained made passive pseudosentences akin to passive reversible sentences. Although this result strengthens the hypothesis that l-pIPS is involved in sentence reanalysis, it leaves unclear whether reanalysis (in pseudosentences and in meaningful sentences) is triggered by passive voice or by reversibility.

This issue was addressed in another rTMS study targeting the same brain region (Vercesi, Sabnis, Finocchiaro, Cattaneo, Tonolli, & Miceli, submitted) (see Chapter 2), in which reversible and irreversible sentences were used. In a forced choice task, participants were presented with simple declarative sentences (reversible and irreversible, active and passive) and with two nouns, corresponding to the agent or to the theme. They were asked to identify the agent in one task, and the theme/patient in another. Consistent with previous studies, rTMS to the l-pIPS affected response times (RTs) only on the reversible passive stimuli. The lack of effects on irreversible passives (and on any actives) indicates that the effect results from the interaction of reversibility and voice. Such an interaction makes it hard to disentangle whether l-pIPS is involved specifically in processing voice or non-canonical word-order, as the two features co-occur systematically in English and Italian passives.

Given the confound between word-order and voice in English and Italian reversible sentences, I used Hindi (Chapter 3) to further clarify the role of the l-pIPS in sentence comprehension. Hindi's relatively free word-order (Kachru, 2006) allows and frequently uses an agent-theme-verb order in both active and passive sentences. This property was particularly relevant for us as it ensures the same word-order in both actives and passives, despite changes of sentence voice. In this experiment, no effects of rTMS were found on either sentence type. Although null results must be interpreted with caution, these observations are consistent with the view that word-order processing is one of the dimensions that may trigger reanalysis.[5] In fact, if voice alone were sufficient to elicit reanalysis in the presence of a canonical word order, an effect of rTMS on Hindi passives should have occurred. However, these results still leave open critical questions on the mechanisms underlying reanalysis. In fact, reversible passives may be more difficult than reversible actives (and hence, require reanalysis) because of the co-occurrence of reversibility, of different morphosyntactic features and (at least in Italian and in English) of non-canonical word order.

Both Finocchiaro et al (2015; submitted), and the first two experiments reported on in this thesis (Vercesi, Sabnis, et al., submitted (Chapter 2); and Chapter 3) have exploited the properties of reversible declarative sentences in order to understand reanalysis in sentence comprehension, particularly in the context of thematic role assignment. However, none of these studies have used them to directly study the processing of reversibility itself. The studies considered so far use reversible declarative sentences with full lexical verbs. Successful comprehension of such sentences requires identifying the agent and the theme/patient of the action – in other words, thematic role assignment. As a consequence, studies that focus on the comprehension of declarative sentences often end up investigating the mechanisms underlying thematic role assignment. However, semantic reversibility is a property of any sentences that express potentially reversible relationships, even if these sentences do not involve thematic role assignment. Consequently, studying only declarative sentences may not sufficiently inform about the processing of reversibility itself.

Locatives are a good example of sentences that can express reversible relationships without requiring thematic role assignment – consider for example sentences like '*The man stands behind the woman*'. Unfortunately, however, even though locative sentences are an excellent context in which to embed semantically reversible relationships, their use in an rTMS study of l-pIPS would be inappropriate. Comprehending sentences that contain relationships like 'behind', 'above', 'below', etc. typically involves generating spatial representations, which are known to recruit parietal regions

[5] Note that this result is also fully consistent with the view that l-pIPS is critical for reanalysis.

(Amorapanth et al., 2010; Baumann and Mattingley, 2014). As a consequence, should rTMS effects emerge with locative sentences, it may be difficult (or impossible) to establish if they result from the involvement of this region in processing reversibility or in constructing spatial representations. Interpretation could be made even more problematic in the light of studies suggesting that the figure-ground relationship seen in locative sentences could stimulate proto-thematic role assignment (Dowty, 1991; Talmy 1985a), which may also be involved in putative rTMS effects.

4.1.1. Comparative Sentences

Comparative sentences may be better suited than locative sentences to uncover the role of the l-pIPS in processing reversibility. While they can be used to encode irreversible relations (e.g., *The shark is more ferocious than the goldfish*; *The goldfish is less ferocious than the shark*), they also frequently express reversible relations without requiring typical or proto-thematic role assignment. Consider examples 1a and 1b.

1a) The princess is more elegant than the queen. – Comparative of Majority (MAC)

The queen is more elegant than the princess. – Comparative of Majority (MAC)

1b) The princess is less elegant than the queen. – Comparative of Minority (MIC).

The queen is less elegant than the princess. – Comparative of Minority (MIC)

Sentences in 1a and 1b are plausible and fully reversible, yet they do not require thematic role assignment. In addition, unlike declarative active and passive sentences, comparatives do not differ in syntactic structural complexity.

At this stage, two properties of adjectives should be considered. Firstly, context is essential for full comprehension of adjectives (Martin & Romani, 1994; Pickering & Garrod, 2007). This is because the meaning of a sentence is also largely dependent on the context determined by the adjective-noun combination (Martin & Romani, 1994). For example, one's understanding/perception of '*big*' could be said to be on different size scales in adjectival noun phrases like '*The big pillow*' and '*The big building*'. In the case of reversible comparative sentences, establishing the context of the adjective is more difficult, as the first noun precedes the adjective, whereas the second follows it. Therefore, in a sentence like '*The princess is more elegant than the queen*', it may be difficult to fully comprehend the meaning of '*elegant*' before the second noun occurs.

Secondly, antonymous adjectives such as 'tall-short' imply opposite meanings. For example, a sentence such as '*John is tall.*' may imply that John is taller than the average person. In other words, the sentence can be taken to mean that an individual with an average body height is shorter than John. On the other hand, comparative sentences that express reversible relations, like '*John is taller than Steve*', relate two specific entities to each other. Therefore, adjectives used in the context of comparative sentences, as in the current experiment, refer specifically to the depicted entities. A physical feature of one of the characters (i.e., John) is explicitly described. On the contrary, the same physical feature is not explicitly stated for the second character (Steve). However, the use of '*taller*' for *John* implies that *Steve* is '*shorter*'. Since the feature is not described using an explicit adjective, the character is considered to be 'unmarked'. Clark and Clark (1968) suggested that in sentence processing, 'unmarked' characters are easier to encode, store and eventually retrieve compared to 'marked' characters, because a 'marked' character needs to be encoded with an additional feature (i.e., '*John*' is encoded as '*tall John*') as opposed to 'unmarked' characters ('*Steve*' is simply encoded as '*Steve*'). Therefore, caution must be used while using such antonymous adjectives.

4.1.2. Current Experiment

Previous rTMS studies have established the involvement of the IPS in sentence comprehension. They show that the l-pIPS is crucial for comprehending reversible sentences, when thematic reanalysis is required – as in the case of passives with a non-canonical word order. However, given that these studies typically used sentences that require thematic or proto-thematic role assignment, it is not possible to establish if l-pIPS is involved in the processing of non-canonical word order specifically, or also of reversibility *per se*. In an attempt to better understand this issue, the current study looks at comparative sentences. It takes advantage of the nature of comparative sentences – reversible, and free of thematic roles (as shown in Examples 1a and 1b). The following four types of reversible sentences were tested in a group of non-brain-damaged Italian speakers: declarative active (DA), declarative passive (DP), comparative of majority (MAC), and comparative of minority (MIC).

Declarative actives and passives in Italian differ structurally. In fact, for comparison, they can be said to be structurally similar to their counterparts in English (see examples 1c and 1d). On the other hand, comparatives of majority and minority in Italian share an identical word-order and a morphosyntactic structure. These structural similarities between the two comparatives were the main reason for choosing this sentence type. Like the declaratives, comparatives of minority are also similar to their counterparts in English (see example 1f). However, comparatives of majority differ from their English counterpart in this regard. Comparatives of majority in English are often marked by the used of the *-er* version of an adjective such as in *The girl is tall***er** *than the boy*.

1c) DA – *La madre bacia la figlia.*
The mother kisses the daughter.
1d) DP – *La figlia è baciata dalla madre.*
The daughter is kissed by the mother.
1e) MAC – *La madre è più elegante della figlia.*
The mother is more elegant than the daughter.
1f) MIC – *La madre è meno elegante della figlia.*
The mother is less elegant than the daughter.

Given the pro-drop nature of Italian, it is also grammatically legal to present these sentences without the first argument (e.g., DA- *bacia la figlia*, DP – *è baciata dalla madre*, MAC – *è più elegante della figlia*, and MIC – *è meno elegante della figlia*). Similar to Finocchiaro et al (2015), the current study used truncated versions of bboth declarative and comparative sentences.

Although systematic studies on Italian comparatives are unavailable, a Google n-gram search revealed that *più* expressions were more frequent than *meno* expressions. This could also suggest that the comparative of majority is a 'canonical' sentence type, as opposed to the less frequent comparative of minority (note that in this case 'canonicity' refers to structural frequency and not word-order). This may affect processing of the two sentence types.

There are two possible outcomes of the study. First, if the l-pIPS is crucial for the reanalysis of thematic roles, rTMS should affect performance on the passive sentences, but not on the active sentences, similar to previous studies (Finocchiaro et al., 2015; Finocchiaro et al., submitted; Vercesi, Sabnis, et al., submitted). In addition, it should not affect performance on either type of comparatives. On the other hand, if the l-pIPS is critically involved in the processing of reversibility as such, I expect to see similar effects of rTMS on all sentences – declaratives as well as comparatives.

It is important to note that the processing of reversibility may have different implications in declarative (i.e., active and passive), and comparative (i.e., majority and minority) sentences, due to specific features of the two sentence types. In declarative sentences, reversibility refers to the potential of both characters in the sentence to perform the given action. In comparative sentences, on the other hand, processing reversibility implies allocating arguments on a scale (or on two opposite polarities, in the case of antonyms). This may affect the behaviour on comparative sentences upon stimulation.

Comparatives of majority are of particular interest, as they share some properties with both active (namely frequency) and passive (namely unpredictability) sentences. Like active sentences (as compared to passives), they are more frequent than comparatives of minority. The second property is unpredictability. It is important to keep in mind that the use of truncated sentences with first argument omission may introduce different levels of unpredictability in the four sentence types. In the case of declaratives, unpredictability is likely to be higher for passive sentences than active sentences because of the non-canonical word order – i.e., the agent occurs after the predicate in passives. In case of both comparatives of majority and minority, the identity and placement of the dropped first argument on the scale denoted by the adjective is not predicted by the adverb *più*/*meno*, but crucially depends on the adjective that follows (e.g., *alto* (tall)/*basso* (short)). I speculate that both types of comparatives could be more similar to passives than actives in terms of unpredictability. This is because while truncated actives require identifying the missing argument, passives entail identifying the missing argument and thematic reanalysis thereafter. Similarly, both comparatives entail identifying the missing argument and placing it on a scale after encountering the adjective. Simply put, like passives, comprehending reversible truncated comparatives and passive may include additional processes.

Therefore, comparatives of majority are more similar to active sentences in terms of frequency, but more similar to passive sentences in terms of unpredictability. On the other hand, comparatives of minority are similar to passive sentences on both accounts. Thus, if the frequency of a structure affects ease of processing, active declaratives and comparatives of majority may exhibit similar behaviours, and the same should apply to passives and comparatives of minority. On the other hand, if the predictability of a structure's interpretation plays a role in its processing, passive declaratives and both comparatives should behave similarly.

4.2. Methods

4.2.1. Participants

Eighteen non-brain-damaged, right-handed, native Italian speakers (13 females; mean age: 24.05; range 20-29), with college education or higher (15+ years) took part in the experiment. All participants had normal or corrected-to-normal vision, and normal hearing. None of them had a history of psychiatric or neurological conditions. All participants were screened for any TMS contraindications. They were blind to the purpose of the study until the completion of the experiment. The study was approved by the University of Trento ethics committee and all participants signed an informed consent form.

4.2.2. *Stimuli Development*

A list of (i) common nouns (e.g., *idraulico*, plumber), (ii) adjectives describing human features (e.g. *alto*, tall), and (iii) two-argument verbs (e.g., *abbracciare*, to hug) was prepared. The words selected initially were screened so that the final list included only easily picturable characters/actions. Intransitive verbs and low-frequency words from all three categories were also excluded. Lemma frequencies were obtained from an Italian corpus (COLFIS; Bertinetto et al., 2005). In order to generate declarative reversible sentences, in each stimulus two nouns were assigned to a verb (see example 2a). To construct comparative reversible sentences, the same noun pair was matched with an adjective (see example 2b).

2a. *nonno* (grandfather) + *nipote* (grandson) + *abbraccciare* (to hug)

'Il nonno abbraccia il nipote.'

(The grandfather hugs the grandson.)

2b. *nonno* (grandfather) + *nipote* (grandson) + *grasso* (fat)

'Il nonno è più grasso del nipote'

(The grandfather is fatter [literally: more fat] than the grandson.)

Combinations were chosen so as to create "truly reversible" stimuli, i.e., sentences in which both characters were equally likely to perform a given action/possess a given feature. Only human characters that shared the morphosyntactic features of gender and number were used. Explicitly unidirectional sentences like *'La madre nutre la bambina'* (the mother feeds the child) were excluded. Verbs denoting spatial relations (e.g., *chase*, *follow*) were also excluded due to the possible involvement of parietal regions in processing spatial relations (Amorapanth et al., 2010; Baumann and Mattingley, 2014). The final lists included 34 verbs and 34 adjectives. Four of the verbs and four of the adjectives were used to generate practice items.

A Google n-gram search, performed in order to obtain information on the relative frequency of the comparatives used in this study, showed that 27 of 30 adjectives occur more frequently with *più* (more) than with *meno* (less).

The pairs of nouns and their assigned verbs and adjectives were used to form DA, DP, MAC, and MIC sentences. Two versions of active and passive declaratives were created, such that the two nouns appeared in both agent and theme positions (see example 3a and 3b). Similarly, in majority and minority comparative sentences, the two nouns appeared in first and second position in the two versions (see examples 3c and 3d).

3a. DA – *La madre bacia la figlia.* – version 1
(The mother kisses the daughter.)
La figlia bacia la madre. – version 2
(The daughter kisses the mother.)

3b. DP – *La figlia è baciata dalla madre.* – version 1
(The daughter is kissed by the mother.)
La madre è baciata dalla figlia. – version 2
(The mother is kissed by the daughter.)

3c. MAC – *La madre è più elegante della figlia.* – version 1
(The mother is more elegant than the daughter.)
La figlia è più elegante della madre. – version 2
(The daughter is more elegant than the mother.)

3d. MIC – *La madre è meno elegante della figlia.* – version 1
(The mother is less elegant than the daughter.)
La figlia è meno elegante della madre. – version 2
(The daughter is less elegant than the mother.)

A total of 120 sentences were used in the experiment, split into four blocks of 30 sentences each. Two blocks consisted of declarative sentences (15 DA and 15 DP per block), and the other two blocks consisted of comparative sentences (15 MAC and 15 MIC in each block). Within each block, half the items were matched, i.e., the picture and sentence corresponded, the other half were mismatched, i.e., the picture and the sentence did not correspond depicted the opposite relationship. Due to the odd number of sentences, each sentence type consisted of 8 matched items and 7 mismatched items in one block, and 7 matched and 8 mismatched items in the subsequent block.

Pictures were drawn to illustrate the sentences. Each picture represented a reversible action described in the DA and DP sentence and a feature described in the MAC or MIC sentence (see Fig. 4.1 for example). All the adjectives described a physical feature of a character in the picture.

Figure 4.1: *A sample picture. In each block, the picture was presented with either a declarative active (DA), declarative passive (DP), Comparative of Majority (MAC) or Comparative of minority sentence such as: DA – assale il ladro ((The thief) attacks the firefighter); DP – è assalito dal pompiere ((The firefighter) is attacked by the thief); MAC – è più barbuto del ladro ((The firefighter) is more bearded than the thief); MIC – è meno barbuto del pompiere ((The thief) is less bearded than the firefighter).*

One item was removed from the final list due to ambiguity in the illustration. The final experiment used twenty-nine pictures (116 sentences). During a pilot, on debriefing participants reported that they found full sentences (see examples in Table 4.1) too long to process in the given time frame. Consequently, truncated sentences were used. Given the pro-drop nature of Italian, these sentences are grammatically correct in the language. Sentences were roughly matched for sentence length. Passive declaratives were two-to-three syllables longer than actives; comparatives of minority were one syllable longer than comparatives of majority.

Table 4.1: *Examples of truncated sentences used in the experiment*

Sentence Type	Original Sentence	Truncated Sentence
DA	*La madre bacia la figlia*	*Bacia la figlia*
DP	*La figlia è baciata dalla madre*	*È baciata dalla madre*
MAC	*La madre è più elegante della figlia*	*È più elegante della figlia*
MIC	*La madre è meno elegante della figlia*	*È meno elegante della figlia*

4.2.3 Stimuli Presentation

116 DA, DP, MAC and MIC sentence-picture combinations were presented across four blocks. Each picture was presented four times in one session: twice with the declarative sentences, and twice with the comparative sentences. Each picture was presented only once per block. The pictures were flipped horizontally in alternate blocks such that the position of the actors was reversed on the screen. This was done in order to avoid the use of any spatial heuristics (e.g. identifying that the agent is always on the right of that picture). All four sentence types were distributed equally within and across blocks. Sixteen additional items were used as practice before the actual task began.

4.3 Procedure

Participants were tested in two sessions, separated by one week. Overall, the experiment took approximately 2 hours per participant. The first session involved an initial briefing regarding the experiment, calibration of the sensors on the scalp to fit the pre-constructed 3D mesh of the individual participant (~30 minutes), the TMS experiment (~20 minutes), a short debriefing session (~5 mins). The second session involved readjusting the previously created 3D mesh to the position of the participant's head (~20 minutes), running the TMS experiment (~20 minutes), and a debriefing session after the experiment (~10 minutes). Participants received active TMS over the l-pIPS in one session, and sham stimulation in the other. Session order was counterbalanced across participants. The experiment was preceded by a training procedure consisting of two blocks. The first block was administered without time limits, in order to familiarise the participant with the task and the TMS setup. Participants were given unlimited time to respond and clarify any doubts on the experimental procedure. The second block was administered with time constraints, to mimic the actual experiment. After completing the second practice block, participants were given yet another opportunity to clarify any remaining doubts before the main experiment began. The experiment consisted of four blocks. Participants were given a mandatory break of 1 minute between blocks.

During the experiment, participants sat comfortably in front of a computer monitor. The task was presented using E-Prime. TMS and sham sessions, and experimental blocks, were counterbalanced across participants. Each trial started with a fixation cross (500ms) followed by the stimulus. The stimulus disappeared immediately after the participant's response or after 3000ms (see Figure 4.2), whichever came first. Stimulus-onset asynchrony was kept constant across participants. Each item consisted of a sentence and a picture, presented simultaneously. Participants were asked to decide as quickly as possible whether the sentence and the picture matched, and to respond by a button-press. The answer could be produced at any moment during the trial. The same stimuli were presented in the real and sham conditions, but in different randomised orders. Reaction times (RTs) and response accuracy were recorded.

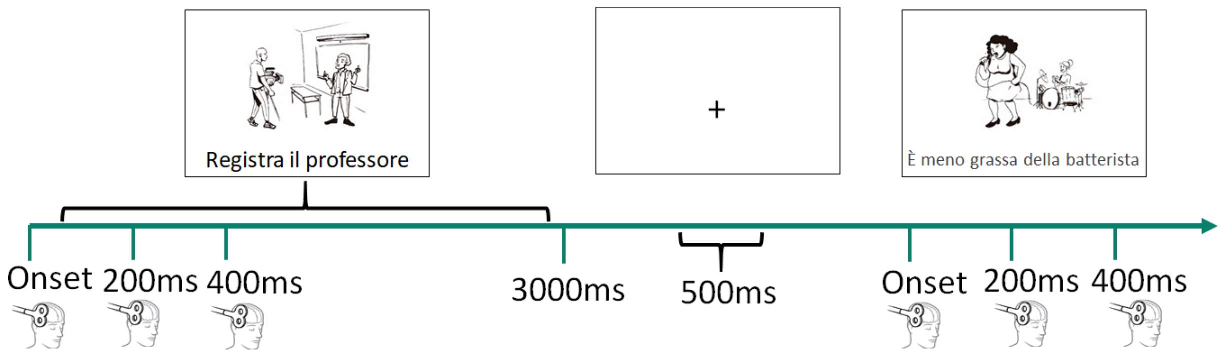


Figure 4.2: *Experiment timeline*

4.3.1. MRI acquisition and Co-registration

The l-pIPS was isolated on the 3D brain reconstruction using macroanatomical landmarks. 3D brain reconstructions were created for individual participants from high-resolution T1-weighted sequences (176 axial slices, in-plane resolution 256 x 224, 1-mm isotropic voxels, generalized auto-calibrating partially parallel acquisition with acceleration factor 1⁄42, time repetition 1⁄42700 ms, time echo 1⁄44.180 ms, time to inversion 1⁄4 1020 ms, flip angle 1⁄4 7°), obtained using a MedSpec 4-T head scanner (Bruker BioSpin, Ettlingen, Germany) with an 8-channel array head coil before the TMS experiment. The 3D reconstructions of the brain and scalp from participant MRI scans, the participant's head, and the TMS coil were co-registered using SofTaxic Neuronavigation System (EMS, Bologna, Italy) before every TMS session. During the experimental task, coil position was monitored online using SofTaxic Neuronavigation System (EMS, Bologna, Italy). The same procedure was followed before all the sham sessions.

4.3.2. Stimulation Parameters

Participants received three trains of biphasic pulses at 5 Hz, at intervals of 200 ms from stimulus onset, as in Finocchiaro et al. (2015). The first pulse was delivered at onset, and the last pulse at 400 ms. TMS pulses were delivered via a MC-B70 butterfly coil and a MagPro Compact stimulator (MagVenture). Prior to stimulation, the visible resting motor threshold (RMT) was identified for each participant. This was established as the lowest stimulation intensity capable of evoking a visible twitch of the index finger of the right hand on at least five out of ten consecutive stimulations.

During the experiment, participants were stimulated at 90% intensity of the individual visible RMT. In other words, if a participant's visible RMT was 50% of the maximum stimulator output intensity, they would be stimulated at 45% of the stimulator intensity. Participants were stimulated at a mean intensity of 46.28% (SD = 3.14%) of maximum stimulator output intensity. E-Prime was used to trigger the magnetic stimulator using a parallel port. TMS was delivered in an event-related fashion, time-locked to the presentation of visual stimuli. The same procedure was followed during the sham sessions. During the administration of sham-TMS, a spacer was placed between the coil and the participant's scalp. During both conditions, the coil was perpendicular the pIPS, at 90° to the midline, and was pointed medially.

4.3.3. Data Pre-processing

Response Times (RTs) and accuracy were recorded. Preliminary analyses of RTs showed consistently faster RTs in the second session regardless of stimulation type (TMS or sham) across all four sentence types. Since performance accuracy was comparable across sessions, faster RTs in the second session could indicate a learning effect. To correct this, the learning effect was first estimated by subtracting the RTs of the first session from the second session for each trial in each participant. Then the mean difference of this *delta* was calculated. This constant value was added to each trial of the second session to correct for the learning effect. Statistical analyses were run on corrected RTs, by contrasting TMS and Sham conditions, independent of session order. While it would have been possible to correct the RTs by including session as a covariate, we chose to correct for individual RTs across participants for a more precise analysis. While the second session was consistently faster than the first session (regardless of stimulation type) across participants, there were individual differences in terms of how much learning occurred. Moreover, these differences also varied between sentence types within the same participants. Consequently, individual correction allowed us to account for all these minor differences. Performance accuracy percentages were converted to standardized scores using a natural logarithmic transformation before analysing the data.

4.4. Results

Mean accuracy and RTs across conditions are summarised in Tables 4.2-4.4 and figures 4.3 and 4.4. 119 of 2088 (5.6%) trials were excluded from analyses for the TMS condition, and 127 of 2088 (6%) trials were exclude from the analyses for the Sham condition.

4.4.1. Reaction Times (RTs)

Statistical analyses were run on RTs after correcting for the learning effect across the two sessions as described in 4.3.3 above. A 3-way repeated measures ANOVA with the factors *STIMULATION* (TMS vs Sham), *CORRESPONDENCE* (Matched vs Mismatched), and *SENTENCE TYPE* (4 levels: DA, DP, MAC, and MIC). There was only a significant main effect of *SENTENCE TYPE* ($F(3, 204) = 0.9$, $p<0.001$). There were no significant effects of *STIMULATION TYPE* ($F(1, 68) = 0.3$, $p = 0.85$) or *CORRESPONDENCE* ($F(1, 68) = 1$, $p = 0.26$), nor any interactions between *STIMULATION TYPE * CORRESPONDENCE* ($F(1, 68) = 0.2$, $p = 0.9$), *CORRESPONDENCE * SENTENCE TYPE* ($F(3, 204) = 0.8$, $p = 0.4$), *STIMULATION TYPE * SENTENCE TYPE* ($F(3, 204) = 2$, $p = 0.1$), or *STIMULATION TYPE * CORRESPONDENCE * SENTENCE TYPE* ($F(3, 204) = 0.04$, $p = 0.9$). Post-hoc analyses examining the effect of sentence type showed no significant RT differences between DA and DP sentences, nor between MAC and MIC sentences. RTs to both DA and DP sentences were significantly shorter than those to MAC and MIC sentences.

To better understand the differences between DA and DP, and between MAC and MIC, we ran two separate 3-way repeated measures ANOVA with the factors *STIMULATION* (TMS vs Sham), *CORRESPONDENCE* (Matched vs Mismatched), and *SENTENCE TYPE* (2 levels: DA vs DP) or (2 levels: MAC, and MIC). At this point, we note that these separate 3-way ANOVAs may not be traditionally justified given that the overall ANOVA showed no significant differences. However, we believe that these analyses may give us further insight into the workings of the two sentence types. The information gleaned from these analyses may help formulate stronger experiments in the future.

No significant effects were found on the ANOVA with DA and DP sentences (*STIMULATION TYPE * CORRESPONDENCE * SENTENCE TYPE (*$F(1, 68) = 0.1$, $p = 0.6$*)*. The ANOVA with MAC and MIC sentences showed a significant effect of *SENTENCE TYPE (*$F(1, 68) = 9$, $p = 0.003$*),* and a significant interaction effect of *STIMULATION TYPE * SENTENCE TYPE (*$F(1, 68) = 5$, $p = 0.02$). To explore this interaction further, t-tests were run within the sham and TMS condition. MAC and MIC sentences showed comparable RTs in the sham condition ($t(35)$=-0.42, p = 0.67). In the TMS condition however, MAC sentences had significantly shorter RTs than MIC sentences ($t(35)$ = -4.87, p < 0.001).

To further understand the differences between declarative and comparative sentence types, t-tests were run within the sham and TMS condition. In the sham condition, RTs to DA sentences were significantly faster than both MAC ($t(35)$=-9.25, p < 0.001) and MIC sentences ($t(35)$=-6.34, p < 0.001). Similar results were seen in the TMS condition where DA sentences were significantly faster than MAC ($t(35)$=-7.81, p < 0.001) and MIC ($t(35)$=-10.15, p < 0.001) sentences. In the sham condition, DP sentences also yielded significantly shorter RTs than MAC ($t(35)$=-9.07, p < 0.001) and MIC ($t(35)$=-6.07, p < 0.001) sentences. In the TMS condition, DP sentences had significantly shorter RTs than MAC ($t(35)$=-6.87, p < 0.001) and MIC ($t(35)$=-9.03, p < 0.001) sentences. Differences within sentence type across sham and TMS conditions were also tested. No significant differences were found, but MAC sentences appear to be approaching significance: DA Sham vs TMS ($t(35)$ = -1.39, p = 1.17), DP Sham vs TMS ($t(35)$ = -0.16, p = 0.87), MAC Sham vs TMS ($t(35)$ = -1.7, p = 0.09), and MIC Sham vs TMS ($t(35)$ = 1.18, p = 0.24).

Table 4.2a: *Mean RTs (in ms) to Sentence Types across conditions (SD in parentheses).*

		Sentence Type			
		Active	Passive	Comparative of Majority	Comparative of Minority
	Sham	1903.47	1916.94	2223.27	2243.44
Condition		(223.6)	(252.03)	(190.27)	(273.13)
	TMS	1871.88	1913.08	2158.83	2313.91
		(220.1)	(230.37)	(205.75)	(195.67)

Table 4.2b: *Mean RTs and SD on Sentence Types in Matched and Mismatched items.*

	Sentence Type			
	Actives	Passives	Comparatives of Majority	Comparatives of Minority
	1843.80	1886	2189.58	2261.58
Match	(199.22)	(233.89)	(166.44)	(165.47)
	1931.55	1944	2192.52	2295.77
Mismatch	(219.32)	(230.51)	(163)	(151.06)

Figure 4.3a: *RTs on DA, DP, MAC, and MIC sentences within conditions*.

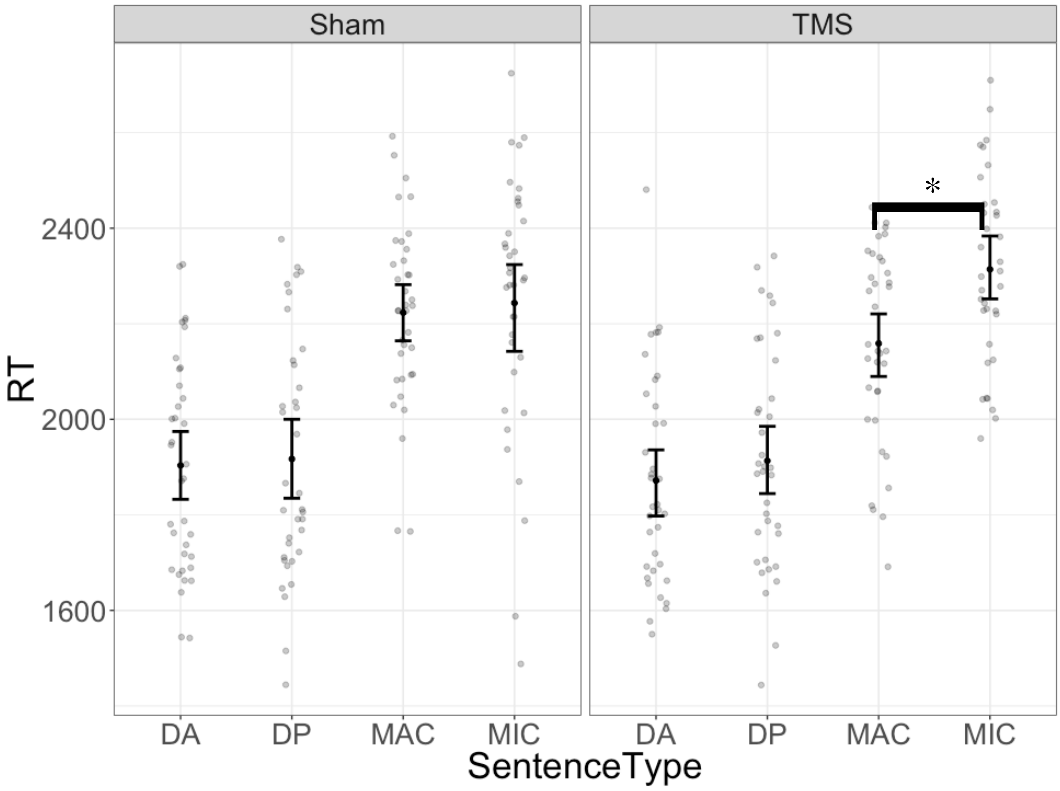
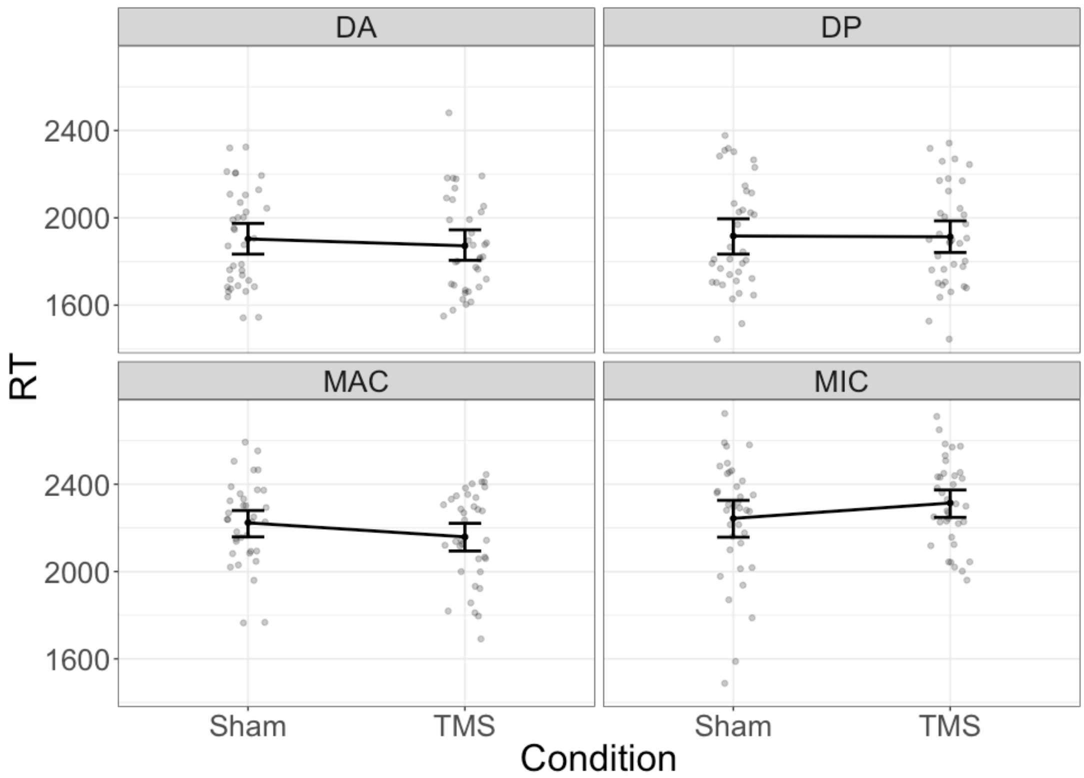


Figure 4.3b: *RTs on DA, DP, MAC, and MIC sentences across conditions*.



4.4.2. Accuracy

Accuracy analyses were run on standardised scores (as described in 4.3.3). A 3-way, repeated measures ANOVA was conducted with the factors *STIMULATION TYPE* (TMS vs. Sham), *CORRESPONDENCE* (Matched vs. Mismatched), and *SENTENCE TYPE* (DA, DP, MAC, and MIC). A significant interaction was found between *CORRESPONDENCE* * *SENTENCE TYPE* ($F(3, 204) = 18.86, p<0.001$).

Post-hoc analysis showed that, regardless of stimulation type, DA sentences were interpreted with significantly greater accuracy in the matched than in the mismatched condition ($t(35) = 3.67$, p < 0.001). The same held true for DP sentences ($t(35) = 4.26$, p < 0.001). The reverse outcome was observed for comparatives. Reactions to MAC sentences were more accurate for mismatched than matched sentences ($t(35) = -6.29$, p < 0.001), as were reactions to MIC sentences ($t(35) = -2.67$, p = 0.01) (see Table 4.4).

No main effects or interactions were seen for the factor *STIMULATION TYPE* ($F(1, 68) = 0.86$, $p = 0.35$). Post-hoc analyses showed no significant differences in performance accuracy between DA and DP sentences. However, DA and DP sentences were both significantly more accurate than MAC and MIC sentences.

Paired t-tests were used to understand these differences better. In the sham condition, DA sentences had higher response accuracy than MAC ($t(17) = -3.99$, p < 0.001) and MIC ($t(17) = 8.63$, p < 0.001) sentences. DP sentence also had higher response accuracy than MAC ($t(17) = 4.72$, p < 0.001) and MIC ($t(17) = 9.62$, p < 0.001) sentences. The same pattern was seen in the TMS condition. DA sentences were more accurate than MAC ($t(17) = 2.6$, p = 0.01)and MIC ($t(17) = 6.28$, p < 0.001) sentences. DP sentences were also more accurate than MAC ($t(17) = 3.98$, p < 0.001) and MIC ($t(17) = 7.25$, p < 0.001) sentences. MAC sentences showed greater accuracy than MIC sentences in the sham condition ($t(17) = 5,33$, p < 0.001) and the TMS condition ($t(17) = 5.45$, p < 0.001). The sentence types were also compared across conditions and no significant differences emerged: DA

Sham vs TMS ($t(17) = -0.49$, p = 0.62), DP Sham vs TMS ($t(17) = -0.04$, p = 0.96), MAC Sham vs TMS ($t(17) = -1.22$, p = 0.23), and MIC Sham vs TMS ($t(17) = 0.58$, p = 0.56).

Table 4.3a: *Mean percent accuracy and SD on Sentence Types across conditions (SD in parentheses).*

		Sentence Type			
		DA	**DP**	**MAC**	**MIC**
Condition	**Sham**	87.73 (8.38)	87.54 (7.94)	72.98 (12.07)	59.19 (11.42)
	TMS	87.16 (11.2)	87.16 (7.36)	77.39 (10.78)	61.68 (11.52)

Table 4.3b: *Mean percent accuracy on Sentence Types in Matched and Mismatched items.*

		Sentence Type			
		DA	**DP**	**MAC**	**MIC**
Correspondence	**Matched**	91.11	91.29	65.47	55.15
	Mismatched	83.53	83.13	84.25	65.37

Figure 4.4a: *Accuracy on DA, DP, MAC, and MIC sentences within conditions*.

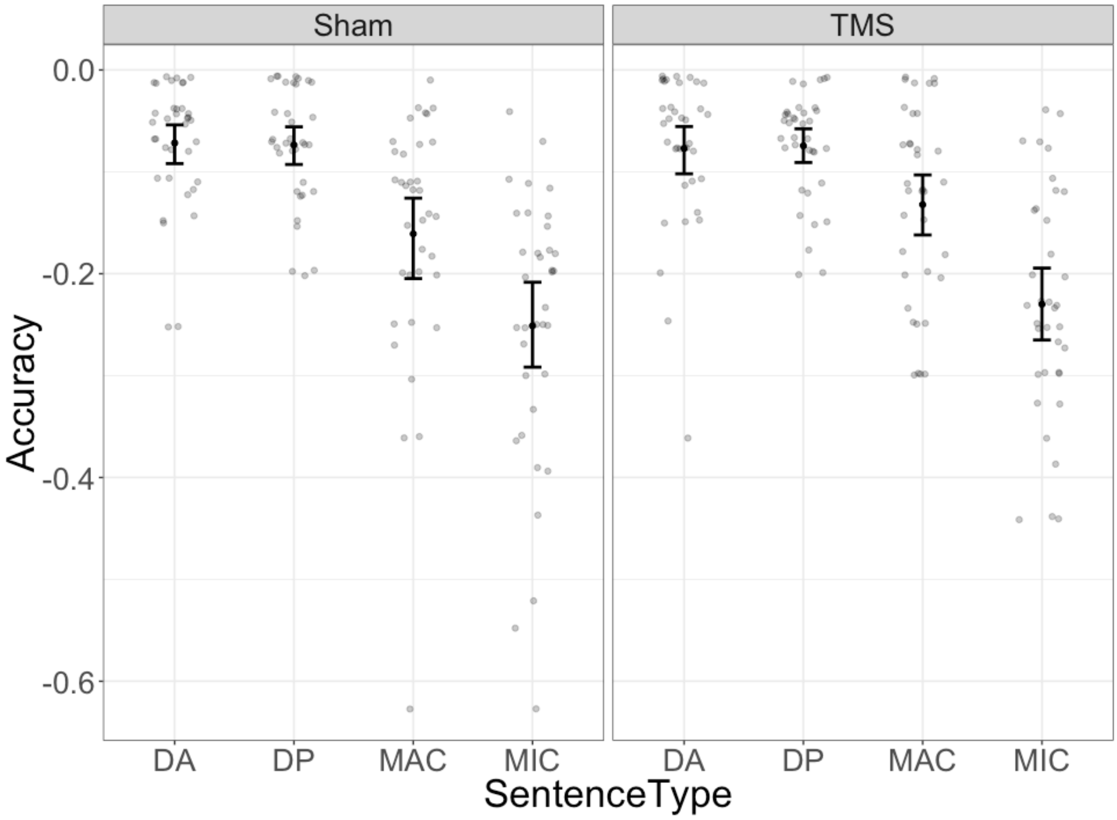
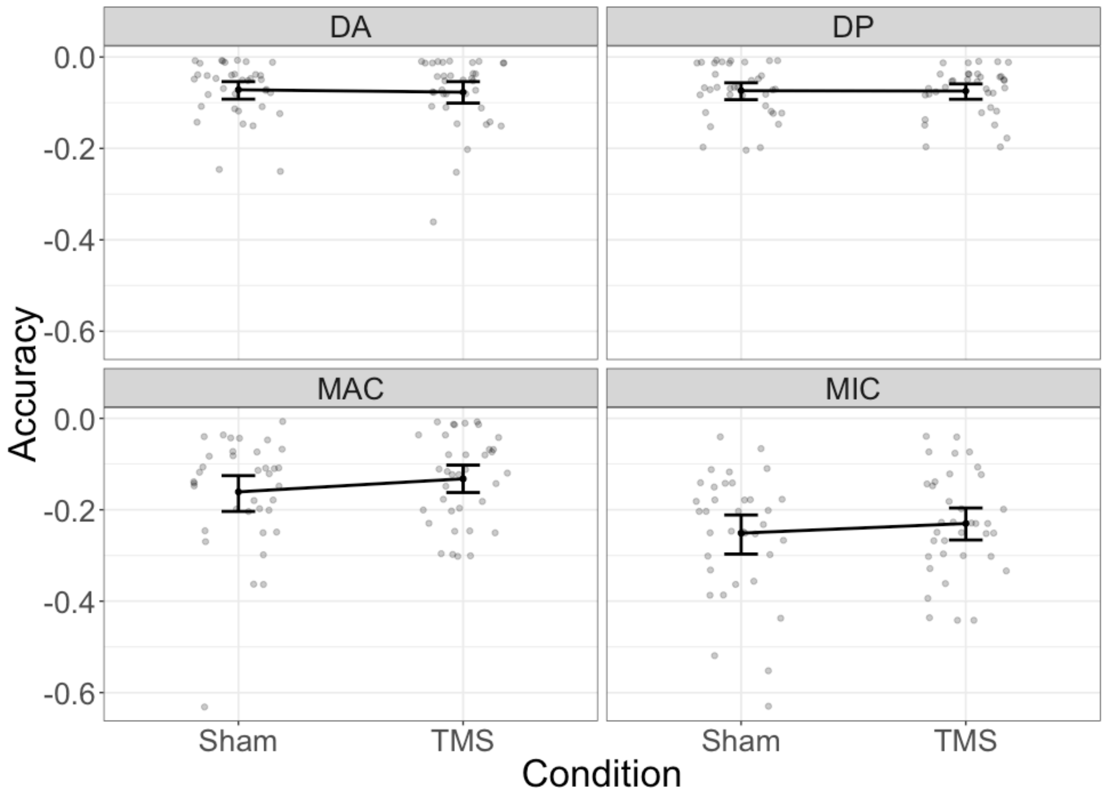


Figure 4.4b: *Accuracy on DA, DP, MAC, and MIC sentences across conditions*.



4.4.3. D-Prime

In addition to the RT and accuracy analyses, a d-Prime analysis was also carried out on matching and mismatching items in order to understand discrimination patterns. A high d-prime score is indicative of better discrimination between matching and mismatching trials. The d-prime is calculated as Z(*Hits*) – Z(*False Alarms*). 'Yes' response to matching trials were considered '*Hits*' and 'Yes' responses to mismatching trials were considered *False Alarms*. A 2-way repeated measures ANOVA was run, with the factors *STIMULATION TYPE* (TMS vs. Sham), and *SENTENCE TYPE* (DA, DP, MAC, and MIC). Results showed a significant main effect of *SENTENCE TYPE* ($F(3, 102)=56.03$, $p<0.001$), but no effect of *STIMULATION TYPE* ($F(1, 34) = 0.22$, $p = 0.63$) nor a *STIMULATION TYPE * SENTENCE TYPE* interaction ($F(3, 102)= 1.3$, $p = 0.27$). Post-hoc tests showed no differences between DA and DP d-prime scores, but significant differences between these and MAC and MIC d-prime scores. A difference was also noted between MAC and MIC d-prime scores. Participants demonstrated a higher *Hit* rate in the Sham than in the rTMS condition for DA and DP sentences, but a higher *Hit* rate in the TMS than in the sham condition for MAC and MIC sentences. The d-prime scores follow the format DA>DP>MAC>MIC (see Table 4.4).

Table 4.4: *d' and standard deviation on all sentences types across conditions*

		Sentence Type			
		DA	**DP**	**MAC**	**MIC**
Condition	**Sham**	2.53 (0.74)	2.46 (0.71)	1.71 (0.58)	0.81 (0.56)
	TMS	2.4 (0.95)	2.37 (0.58)	1.92 (0.63)	1.11 (0.54)

4.5. Discussion

Previous rTMS studies of sentence comprehension provided clear support for the hypothesis that stimulation of l-pIPS affects the processing of passive reversible sentences, presumably as a consequence of the role of this region in sentence reanalysis, that is, of the processes that result in the revision of the thematic role assignment carried out during the first-pass analysis of the sentence. The goal of the current experiment was to try to disentangle the roles of reversibility and word-order in reanalysis. Declarative active and passive sentences were contrasted with comparative of majority and minority sentences. If non-canonical word order is a key factor in activating reanalysis, rTMS to l-pIPS was expected to selectively affect performance on the passive sentences. On the other hand, if reversibility as such is the critical dimension, rTMS should affect all four sentence types.

In the current study, no effect of rTMS on active or passive sentences were observed on RTs or performance accuracy in either the TMS or in the sham condition. Active and passive sentences had shorter RTs and greater accuracy than comparatives of majority and minority across both sham and TMS conditions. *d'*-prime scores also indicate that participants were most accurate on active and passive sentences, followed by comparatives of majority and comparatives of minority sentences respectively.

A 'yes' bias was observed for the declarative sentences (actives and passives) and a 'no' bias for the comparative sentences (majority and minority comparatives). In other words, declarative sentences were interpreted more accurately in the matching condition, regardless of stimulation type, whereas comparative sentences were interpreted more accurately in the mismatching condition, regardless of stimulation type. This is particularly interesting as it is more common to see a 'yes' bias in such experiments. Given that both comparative and declarative relationships were depicted in the same picture, it can be speculated that the differences in 'yes' and 'no' biases may have resulted from complex conflicts. More specifically, from an interaction between the agent and theme depicted in a picture, and the owner of a given feature/property described by the adjective in the same picture. For example, in Figure 4.5b, the property *meno calmo* (less calm) is owned by the theme (*violinista* (violinist)) of the picture. Such ownership of the property in the picture by the picture's theme would result in perceptual conflicts in the characters' saliency. Such a conflict may in part explain these differences in bias between the declarative and comparative sentences.

Figure 4.5: *An example depicting the picture's theme as the owner of the described property.*

The main discrepancy between this and the previous studies, however, resides in the null results for passive sentences – rTMS of l-pIPS did not affect processing of passive sentences. These results contrast with those reported in Finocchiaro et al. (2015; submitted); and by Vercesi, Sabnis, et al. (submitted). This difference may be explained in part by the change in the experimental paradigm. The previous studies included only declarative sentences, whereas the current experiment required participants to switch between declarative and comparative sentences in alternate blocks. It is known that even minor changes to paradigms affect strategies used in comprehension tasks (e.g., Black, Nickels, & Byng, 1991). In the present case, the specific heuristics used for correct interpretation, linked to the co-occurrence of declaratives and comparatives in the same experimental session, could have influenced the processing of passive sentences (Caplan and Futter, 1986; Caplan, Hilderbrandt, & Marshall, 1988). To verify if this is indeed the case, future studies should investigate different sentence types in separate experiments (or, at least in separate sessions).

As regards comparative sentences, RTs to comparatives of majority and minority were statistically indistinguishable in the sham condition, but rTMS to the l-pIPS resulted in significantly faster RTs to comparatives of majority than to comparatives of minority. These differences cannot be attributed to a speed-accuracy trade-off, as the difference in performance accuracy between comparative of majority and minority sentences did not change across conditions.

At face value, these results could be taken as evidence that rTMS to the l-pIPS facilitated the processing of MAC sentences (as it did for passive sentences in previous experiments). However, a significantly greater effect for majority than for minority comparatives is very difficult to account for. In the first place, the two comparative sentences have the same syntactic structure, and therefore may exploit the same heuristics for processing. For example, the distance between the adjective and the nouns was very short (thus aiding sentence processing, as suggested by Haarmann, Davelaar, & Usher, 2003), and identical in the two cases. Two words intervened between the first noun and the adjective (the copula and the comparative term), and one word between the adjective and the second noun (the preposition+determiner that in Italian introduces the second term of the comparison). Secondly, in both cases each stimulus consisted of a sentence presented in association with a picture. Thus, the illustration constrained the linguistic framework in which the sentence must be interpreted, which in turn may have helped establish the appropriate context (Martin and Romani, 1994). This could have also helped predict the second noun (Pickering and Garrod, 2007) thus making both comparatives of majority and minority similarly difficult to comprehend. Finally, in the current experiment, the pictorial depictions make the adjectives unintentionally, but obviously antonymous in both comparatives of majority and minority. For example, the distinction between tall and short is emphasised only by depicting a tall and a short character. However, as mentioned above, the picture constrains the context, thereby aiding 'marked' and 'unmarked' characters in both types of comparatives similarly.

Results are also difficult to accommodate within the very generic assumption that reanalysis is triggered by 'difficult' sentence types. This view was tenable in previous studies, in which declarative passives also happened to be the most difficult sentences to interpret (see Finocchiaro et al., 2015; submitted; Vercesi, Sabnis, et al., submitted; Chapter 3 of this thesis). The same view is not viable in the present context. In this study, the comparatives of minority (and not the comparatives of majority) should be the obvious target of the effect, as the outcome of the Google n-gram search (27/29 adjectives used in the experiment are used more frequently with '*più*' than with '*meno*') suggests that in principle minority comparatives pose a greater difficulty.

An alternative explanation for the results could lie in the stimuli and in the experimental paradigm used in this experiment (see Black, Nickels, & Byng, 1991). Throughout the sessions, the same picture was used to tap comprehension of both declarative and comparative sentences (see section *2.2.1* above). This choice was made to ensure that the visual stimuli used to represent declarative and comparative relationships had the same visual complexity. However, during the post-experimental debriefing sessions, participants indicated that often when presented with a picture and a comparative sentence, their attention was first drawn to the agent of the event represented in the picture. They reconsidered the picture and the sentence in order to establish which character possessed which feature only at a later stage. Consistently better performance on declaratives (faster RTs and greater accuracy) across stimulation conditions is supports these subjective reports

One could argue that a type of reanalysis is also necessary in the case of comparative sentences. However, the process is clearly different to that needed for reversible declaratives. In the case of declaratives, reanalysis refers to the need to reassign thematic roles to the arguments of a sentence, based on a sentence/picture pair. On the other hand, in the case of comparatives, the participant initially identifies the agent of the event represented in the picture, and then must switch focus, and consider the physical properties of the two characters involved in the action. At this stage, the participant evaluates which of the two characters owns the physical property represented in the drawing. This process is not only more complex, but also more time-consuming, as shown by the fact that RTs to comparatives were longer than RTs to declaratives (TMS Condition: 343.47ms, Sham Condition: 325.15ms). Also, in some conditions responses to comparatives were produced almost 2 seconds after the last TMS burst. Given that high-frequency online TMS is thought to affect cortical activity for approximately half as long as the stimulation train (in this case stimulation lasted till 400ms, therefore effects could have lasted till approximately 600ms) (Rotenberg, Hovrath, & Pascual, 2014), it is possible that the effects of rTMS have tapered down by the time the subject was ready to respond.

4.6. Conclusions

The results of this study are difficult to interpret. Unlike in previous experiments, they failed to show effects of rTMS of the l-pIPS on passive declarative sentences. In regard to the comparative sentences TMS reduced RTs to comparatives of majority but did not affect performance on comparatives of minority. This result cannot be accommodated by assuming that reanalysis is triggered by the generic ‘difficulty’ of the target sentence, as in this case minority comparatives should have been affected more than majority comparatives. After considering several accounts, I favour the view that a combination of factors was responsible for the puzzling results. Some factors stemmed from the experimental paradigm, as blocks of declarative and comparative sentences were mixed in the same session. Other factors stemmed from the picture stimuli, each of which represented in the same drawing a reversible event and a physical property, resulting in visually complex stimuli, that often put conflicting emphasis on the event and the property.

In order to disentangle these issues, exploring the various sentence structures in more isolated paradigms (for example, studying declarative and comparative sentences in separate experiments) may help garner clearer results, and thereby a better understanding of the role of reversibility in triggering reanalysis.

Chapter 5

General Discussion

5.1. Summary of Previous Work

Previous neuroimaging and brain stimulation studies have established the role of the IPS in processing language, particularly in terms of sentence comprehension (see **Chapter 1** for references). Based on these studies, Finocchiaro et al (2015) set out to better define the role of the IPS in sentence comprehension. They ran a TMS study wherein three parts of the left IPS – anterior, middle, and posterior, were stimulated online during a sentence-picture verification task. Participants received stimulation to one of the three sites in each session. During the task, participants read Italian sentences in the active or passive voice. A selective improvement on passive sentences was observed, when the posterior third of the left IPS (henceforth, l-pIPS) was stimulated. Consequently, the authors suggested that the l-pIPS plays a role in thematic role assignment, specifically at the stage where thematic roles are reanalysed for correct interpretation.

In a follow-up study, Finocchiaro et al (submitted) ran a repetitive TMS (rTMS) experiment with reversible active and passive sentences, as well as 'active' and 'passive' pseudosentences. Stimulation of the l-pIPS selectively improved RTs on passive sentences and pseudosentences. The authors argued that the pseuedonouns used in these stimuli may function as proto-agents and proto-themes, thereby allowing them to be processed similarly to reversible sentences. In other words, in a pseudosentence the pseudonouns might take on agent-like and theme-like roles, leading to a proto-thematic role assignment. These results were interpreted as being consistent with the hypothesis that passive voice sentences require reanalysis, even in the absence of full semantic meaningfulness of verbs and, importantly, that the l-pIPS is involved in the reanalysis process.

While these studies support the view that reanalysis is required during the interpretation of passive reversible sentences and that the l-pIPS provides neural substrate critical for this process, they do not directly identify the mechanism(s) that may engender such reanalysis.

5.1.1. Motivation of the thesis

In the current thesis, I focused on the l-pIPS to discern the mechanisms that may be involved in triggering reanalysis. I followed up on the findings of Finocchiaro et al (2015) and Finocchiaro et al (submitted) and attempted to answer three main questions:

1. Is reversibility (i.e., the presence of semantically reversible thematic roles) crucial for triggering reanalysis?
2. Are word-order and sentence voice crucial for inducing reanalysis?
3. Do reversible relationships trigger reanalysis in the l-pIPS even when thematic role assignment is not required for sentence comprehension?

To answer these questions, I ran three experiments. I used a forced-choice task with Italian sentences to answer the first question (**Chapter 2**), a sentence-picture verification task using Hindi sentences to answer the second question (**Chapter 3**), and a sentence-picture verification task using Italian sentences to answer the third question (**Chapter 4**). The results of the two studies by Finocchiaro et al (2015; submitted) and those of the three experiments reported in this thesis are summarised in section 5.2.

All three experiments in the current thesis used rTMS. Experiments based on rTMS have three advantages over alternative experimental approaches: i) the technique is safe and non-invasive, and has limited side effects, if used according to international standards (Kroptov, 2016; Merabet & Pascual-Leone, 2019; and Rossi et al., 2009); ii) unlike lesion studies, typically associated with extensive damage to brain structures, rTMS allows delivering stimulation to (hence, interfering with) small volumes of nervous tissue, thus facilitating conclusions on the functional role of circumscribed brain structures (Sliwinska, Vitello, & Devlin, 2014; Paus, 2005; and Sack, 2006); and iii) since its effects are limited in time, it allows one to observe the short-term effects of changes to the region of interest (Sliwinska et al., 2014). Online TMS was used to to answer these questions, as it seems to be well suited to address issues related to sentence comprehension. Administering bursts of rTMS over a very short time-window allowed analysing phenomena with a satisfactory temporal resolution (Bergmann et al., 2016, Devlin and Watkins, 2008) and measuring behavioural changes in real time (Siebner, Hartwigsen, Kassuba, & Rothwell, 2009). An additional advantage of delivering short bursts of online rTMS is that they do not result in adaptive reorganisation (Hartwigsen et al., 2015; Pascual-Leone, Walsh, & Rothwell, 2000; and Walsh and Cowey, 2000).

The previous Finocchiaro studies and the experiments reported in the current thesis are summarised in Tables 5.1 and 5.2 below.

5.2. Summary of Previous and Current Experiments

Table 5.1: *Sentence types used in all the experiments*

Experiment	Sentence Type	Example
Finocchiaro et al., 2015	Reversible Actives	*Baciano le figlie* ((They) kiss the daughters)
	Reversible Passives	*Sono baciate dalle mamme* ((They) are kissed by the mothers)
Finocchiaro et al., submitted	Reversible Actives	*La ragazza abbraccia il ragazzo* (The girl hugs the boy)
	Reversible Passives	*Il ragazzo è abbracciato dalla ragazza (The boy is hugged by the girl)*
	'Active' Pseudosentences	*Il cotro purfa il trilo*
	'Passive' Pseudosentences	*Il trilo è purfato dal cotro*
Vercesi, Sabnis, et al., submitted (Chapter 2)	Reversible Actives	*La bambina bacia la madre* (The child kisses the mother)
	Reversible Passives	*La madre è baciata dalla bambina* (The mother is kissed by the child)
	Irreversible Actives	*La bambina bacia la bambola* (The child kisses the doll)
	Irreversible Passives	*La bambola è baciata dalla bambina* (The doll is kissed by the child)
Chapter 3	Reversible Actives	बच्ची नर्स को छूती है। (The child touches the nurse.)
	Reversible Passives	बच्ची द्वारा नर्स को छुआ जाता है। (The nurse is touched by the child.)
Chapter 4	Reversible Actives	*bacia la figlia*. ((The mother) kisses the daughter.)
	Reversible Passives	*È baciata dalla madre* ((The daughter) is kissed by the mother.*)*
	Reversible Comparatives of Majority	*La madre è più elegante della figlia*. (The mother is more elegant than the daughter.)
	Reversible Comparatives of Minority	*La madre è meno elegante della figlia*. (The mother is less elegant than the daughter.)

Table 5.2: *Summarising rTMS experiments from the thesis and the preceding studies.*

Experiment	Sentence Types	Task Type	Effects of rTMS	Conclusion
Finocchiaro et al., 2015	Reversible Active and Passive sentences (Italian)	Sentence-Picture verification task	Selective effect on accuracy with passive sentences.	IPS is crucial for reanalysis of thematic roles.
Finocchiaro et al., submitted	Reversible Active and Passive sentences (Italian) + 'Active' and 'Passive' pseudosentences	Forced-choice task (Sentence-Noun verification task)	Selective effect on accuracy with passive sentences pseudosentences	Reanalysis can occur regardless of semantic meaningfulness.
Vercesi, Sabnis, et al., submitted (Chapter 2)	Reversible and Irreversible Active and Passive sentences (Italian)	Forced-choice task (Sentence-Noun verification task)	Selective effect on RTs with reversible passive sentences.	Reversibility is crucial for reanalysis.
Chapter 3	Reversible Active and Passive sentences (Hindi)	Sentence-Picture verification task	No effect on either actives or passives.	Non-canonical word-order is crucial for reanalysis.
Chapter 4	Reversible Active and Passive sentences + Comparatives of Majority and Minority (Italian)	Sentence-Picture verification task	Selective effect on Comparatives of Majority	Reanalysis (revision of first-pass sentence analysis even when thematic role assignment is not needed) can trigger reanalysis.

5.2.1. Experiment 1 (Chapter 2)

The first experiment included reversible and irreversible Italian sentences in the active and passive voice. Participants were presented with a sentence that appeared at the centre of the screen. The target sentence, the agent and the theme nouns appeared at the same time, as shown in Figure 1. Participants were required to identify either the agent or the patient of the sentence, in alternated blocks. Four blocks were administered. During the task, participants received rTMS to the l-pIPS.

rTMS increased RTs only on reversible passive sentences. Reversible active sentences, and irreversible active and passive sentences were unaffected. These results have two main implications: i) passive voice or semantic reversibility alone do not elicit reanalysis. Had this been the case, an effect should have been seen on both irreversible and reversible passives, or on both reversible active and passive voice sentences; ii) an interaction of voice and semantic reversibility (or their co-occurrence) is necessary to trigger reanalysis. The l-pIPS perhaps plays an important role in solving computational problems that arise as a result of the simultaneous presence of syntactic (non-canonical word-order) and semantic (reversibility) factors that 'complicate' sentence interpretation, by rendering other heuristics (encyclopaedic knowledge, agent-first strategy, etc.) ineffective. This possibility is supported by previous literature linking the l-pIPS and the comprehension of reversible sentences (e.g., Finocchiaro et al., 2015). Thus, reanalysis may occur due to the need to revise the thematic roles assigned during the first-pass parse.

5.2.2. Experiment 2 (Chapter 3)

The second experiment required participants to perform a sentence-picture verification task during rTMS to the l-pIPS. Stimuli consisted of drawings presented with either active or passive Hindi sentences (see Figure 5.2 for example). In the Hindi passives used in the current experiment, the sentence retains the agent-theme-verb word order, similar to the active sentences. It was posited that if a non-canonical word-order is crucial for reanalysis, then rTMS should have no effect on either actives or passives (or should have similar effects on both), as both sentence types use the preferred word-order.

Results were consistent with the hypothesis – no effects of rTMS were seen on active or passive sentences. The null results on this study are indicative of two things. First, sentence voice alone is not sufficient to trigger reanalysis. Had this been the case, rTMS should have affected performance on passive sentences. Second, results stress the role of word order in reanalysis. In the current study, arguments in both actives and passives appear in the preferred agent-theme-verb order, yet none are affected. Interestingly, both the Finocchiaro et al (2015; submitted) studies, and Vercesi, Sabnis, et al (submitted, see **Chapter 2**) that found an effect of rTMS on passive sentences used passive sentences with non-canonical word orders.

5.2.3. Experiment 3 (Chapter 4)

The final experiment also used a sentence-picture verification task. Pictures were presented along with Italian sentences in the active voice or passive voice, or with comparatives of majority or minority. rTMS was administered to the l-pIPS upon stimulus onset. The goal of this experiment was to understand the role of reversibility. In the context of this experiment, the terms refers both to thematic reversibility (i.e., this is the case for declarative sentences, in which both an agent and a theme have the potential to perform the action), and to reversibility of the ownership of a property in sentences that do not require thematic role assignment (e.g., this is the case of sentences containing a comparative of majority or minority).

Unlike in previous experiments, rTMS had no effect on passive sentences. In case of the comparative sentences, a selective effect was found on comparatives of majority (reflected by faster RTs) but not on comparatives of minority. In this experiment, the same pictures were used to depict both declarative and comparative relationships. Consequently, participants implicitly processed the thematic roles in the first-pass parse (as reported in post-experimental debriefings) before processing the associated comparative sentence. While these subjective reports indicate that with comparatives participants revised their interpretation of the stimulus sentence, the process is markedly different from the thematic reanalysis seen with passives.

The results of this experiment, particularly on passive sentences, are surprising in the light of previous findings (see Finocchiaro et al., 2015; submitted; Vercesi, Sabnis, et al., submitted (**Chapter**

2)). These null results on passives could be indicative of confounding variables. Moreover, the effects of TMS on comparatives are also puzzling. In the case of comparatives, even if it assumed, like in the previous experiments, that reanalysis is triggered by 'difficult' sentence types, TMS should have affected comparatives of minority instead of the comparatives of majority. Given the consistent effect of TMS on passive sentences in the previous experiments, and the effect of the 'easier' type of comparative in this experiment, we posit that the results may have been affected by the use of complex stimuli pictures.

5.3. General Discussion

Taken together, the three experiments in the current thesis, and the two studies by Finocchiaro (2015; submitted) support the view that the l-pIPS is involved in sentence comprehension. In particular, the Finocchiaro studies, and **Chapter 2** found a selective effect of rTMS on passive sentences, but not on active sentences. Finocchiaro et al (2015) argued that these results reflected the region's involvement in the reanalysis of reversible passive sentences, even in the absence of semantic meaningfulness (Finocchiaro et al., submitted). These finding are in line with independent psycholinguistic studies arguing that sentences with non-canonical word-orders often require reanalysis. In fact, the same pattern has been observed in several languages such as English, Dutch, German, Italian, Turkish, and Japanese g (Bastiaanse & Edwards, 2004; Burchert and De Bleser; 2004; Grodzinsky, Piñango, Zurif, and Drai, 1999; Linebarger, Schwartz, and Saffran; 1983; Luzzatti et al., 2001; Duman, Altinok, Özgirgin and Bastiaanse, 2011, Kinno, Kawamura, Shioda, and Sakai, 2008). However, neither of the studies by Finocchiaro discerned which specific aspect of passive reversible sentences – viz., non-canonical word-order, passive voice, or reversibility – triggered the reanalysis.

The findings of Vercesi, Sabnis, et al (submitted, see **Chapter 2**), along with those of the studies by Finocchiaro suggest that non-canonical word-order could be a key factor required to trigger reanalysis. All three experiments used Italian reversible passive sentences, i.e., sentences with non-canonical word-order. These results are consistent with the null results on the Hindi experiment in **Chapter 3**, wherein rTMS had no effect on Hindi reversible passive sentences. If non-canonical word order were irrelevant for inducing the re-analysis of passives, rTMS should have affected the processing of Hindi passives as well.

The observation that in a number of studies rTMS demonstrates a selective effect on reversible passive sentences and pseudosentences (Finocchiaro et al, 2015; Finocchiaro et al, submitted; Vercesi, Sabnis, et al, submitted (**Chapter 2**)) suggests that sentence voice in itself may be a factor engendering reanalysis. This possibility, however, is challenged by results of the Hindi experiment, showing indistinguishable effects of rTMS on actives and passives (**Chapter 3**). If sentence voice alone was sufficient to trigger reanalysis, rTMS should have affected Hindi passives as well, just like it did Italian passives. Overall, findings are consistent with the view that for reanalysis to occur, other factors like non-canonical word-orders and semantic reversibility need to co-occur with sentence voice.

As regards the role of reversibility, the results of the experiment on reversible and irreversible sentences (**Chapter 2**) support the view that reversibility is involved in reanalysis, as only reversible (but, not irreversible) passives were affected by rTMS. However, rTMS effects were only observed with reversible sentences in the passive voice. This observation is consistent with the 'complexity' view of reanalysis – i.e., the view that a combination of features (in this case, reversibility and passivity) is needed to start the reanalysis process.

Even though an attempt was made at clarifying the role of reversibility *per se* (i.e., independent of its association with dimensions like passive voice and word-order) as a potential stimulus for reanalysis, results were unsatisfactory. The experiment reported in **Chapter 4** failed to replicate the critical finding of previous experiments on Italian, as rTMS had no effects on reversible passives. Therefore, the results observed in other 'branches' of the experiment must also be interpreted with caution. For example, the effect on comparatives could be taken to reflect the influence of rTMS in the comprehension of reversible relationships even when the grammatical context does not require the assignment of thematic roles. However, the observed result is difficult to accommodate within the 'complexity' account. As per the account based on previous experiments, l-pIPS is involved in the reanalysis process, and rTMS of this area would affect the comprehension of 'difficult' structures. However, in this case one expects an identical effect on comparatives of majority and minority, as they have the same syntactic structure, or a greater effect on comparatives of minority, as they are less frequent than comparatives of majority. Yet, an effect on comparatives of majority was observed. In short, the results of this experiment cannot be interpreted along the lines suggested to account for all the other experiments, nor can they be fully explained by an alternative, but coherent account. A possible reason for the results of this experiment lies in the choice of stimuli materials. The picture stimuli presented to the participants were noticeably more complex than those used in the previous studies. It is possible that analysing the same picture/illustration for the assignment of thematic roles (declarative sentences) and for property ownership (comparative sentences) may have altered/complicated strategies for picture interpretation beyond the limits that could be explored by the rTMS bursts administered during the experiment. Overall, after considering several possibilities, I am inclined to think that the lack of effects on reversible passives may result from stimulus complexity.

It should be kept in mind that comprehension of any type of sentence exploits numerous cognitive resources, only some of which are considered in the present project. One relevant resource is working memory (WM). Several studies have implicated regions of the parietal lobe in working memory processes (e.g., neuroimaging studies: Novais-Santos, Gee, Shah, Troiani, & Work, 2007; TMS studies: Lauro, Reis, Cohen, Cecchetto, & Papagno, 2010; Romero, Walsh, & Papagno, 2006). While the neuroimaging study saw increased activation of the inferior parietal cortex, the two TMS studies identified the inferior parietal lobule (BA40) as critical for the phonological loop. Lauro et al., 2010 found that TMS to this area affected both syntactically simple but long sentences, and syntactically shorter but complex sentences, especially when word order was reversed. However, when it comes to interpreting the role of the l-pIPS (the region stimulated in the current experiments) in sentence comprehension, the reanalysis account still seems preferable. For one thing, the parietal region stimulated by Lauro et al (2010) lies anterior to the area stimulated in the experiments reported on here. Furthermore, lesion studies that highlighted the role of parieto-temporal areas in the comprehension of reversible sentences (e.g., Thothathiri et al., 2012; Rogalsky et al., 2018) demonstrated that the areas deemed to be critical for sentence comprehension were not modified when sentence comprehension accuracy was adjusted for performance on working memory performance.

More in general, while working memory resources are unquestionably a key component of sentence comprehension, they are by no means the only linguistic/cognitive skills required in sentence comprehension. The correct interpretation of a sentence involves the processing of many dimensions that include, beyond syntactic and morphosyntactic features (sentence type, active/passive voice, reversibility, word order, etc.), length (numbers of constituents, words, syllables, phonemes, etc), context, discourse features, etc. Different permutations and combinations of these factors (as seen in different sentence structures such as actives, passives, etc) affect working memory demands to different extents in different sentences. As a result, disentangling the role of working memory from that of other processes involved in sentence interpretation is extremely difficult, and requires a complex set of experiments, each study focusing on a very limited number of strategically selected variables.

It is also important to note at this point that the results of the studies presented in this thesis could reflect the role of the l-pIPS in the multi-demand control system. In other words, the IPS is activated in a variety of cognitively demanding tasks (Duncan, 2006, 2010; Duncan & Owen, 2000, Whitney et al, 2012). Several studies have implicated the IPS in a variety of cognitive tasks that involve executive and/or attention processes including spatial orientation, tone discrimination, finger movement sequencing, and categorization of faces, and semantic stimuli (Hedden & Gabrieli, 2010; Ciaramelli, Grady, & Moscovitch, 2008; Collette, Hogge, Salmon, & Van der Linden, 2006; Duncan, 2006; Wager, Jonides, & Reading, 2004).

In the current thesis, the results of **Chapter 2** specifically may be explained by this account. The reversible passive sentences appear to be the most difficult condition (in terms of longer RTs) even in the sham condition. The effects of TMS on this sentence type could have been a result of the regions involvement in task demands, i.e., it plays an important role in processing more complex stimuli. However, this account does not explain the lack of effect of TMS on reversible passive sentences in **Chapter 4**. Neither does it account for the lack of effects on the comparatives of minority which should have been more 'difficult' based on both frequency and length (as the comparatives of minority are one syllable longer than the comparatives of majority). Consequently, the involvement of the l-pIPS in reanalysis seems more probable.

It is also worth noting that the regions activated in the studies mentioned above appear to be more extensive, covering the whole IPS, or more anterior in case of stimulation, than the site stimulated in the current studies. Therefore, in talking about the involvement of the l-IPS in reanalysis, I talk specifically about the l-posterior third of the IPS (l-pIPS). I do not claim that the l-IPS or l-pIPS are solely responsible for reanalysis. Instead it is likely that the region, as seen in previous studies, is responsible for processing several cognitive activities. Reanalysis is very likely one of the functions the l-pIPS is responsible for and the current studies appear to provide evidence for this.

5.3.1. Linguistic Factors

Apart from the use of rTMS, this thesis has benefited from the use of two things: a cross-linguistic approach, and different sentence types. While the contrast of Italian and Hindi passives offered a chance to compare passive voice with and without a non-canonical word-order, comparative sentences gave a chance to study reversibility in sentences without explicit thematic role assignment. Going forward, one may obtain a clearer understanding of the roles of these factors. For example, one may gain a better understanding of the role of non-canonical word-order by contrasting Hindi agent-theme-action passives with theme-agent-action passives. Such a contrast in Hindi would entail contrasting passive sentences in the preferred SOV order with the non-preferred OSV order. This contrast would allow studying a reversal of grammatical roles, while mapping thematic roles onto the same grammatical roles, i.e., in both cases agent = subject, and theme = object.

I also note in the Hindi experiment that performance on Hindi passives may be affected by factors such as case markers, postpositions, morphosyntax, and frequency of syntactic structure. The effect of structure frequency in processing passive sentences has been studied in languages in which the passive voice is used frequently, like Standard Indonesian (28-35%) (Anjarningsih, Haryadi-Soebadi, Gofir, & Bastiaanse, 2012; Jap, Martinez-Ferreiro, and Bastiaanse, 2016). Similarly, contrasting languages like Hindi which have richer case-marking, morphosyntactic systems with languages like English which have less rich systems may help us understand the role of these features in sentence comprehension in reanalysis.

On the other hand, in the case of factors like reversibility, studying different sentence types in isolation may be helpful. In other words, studying sentences like declaratives and comparatives in separate experiments may help find clearer results, and in turn better understand the role of reversibility in reanalysis. Furthermore, studying different sentence types may also help understand how various regions of the brain interact for successful sentence comprehension. For example, parts of the right parietal region are thought to be involved in the processing of locative sentences as these sentences require generating spatial representations (Amorapanth et al., 2010; Baumann and Mattingley, 2014). Administering such sentences may help investigate interactions between left and right parietal regions.

5.3.2. Technical Considerations

In addition to the neural mechanisms, several technical factors and methodological differences may also have influenced the results of the current experiments. The first difference lies in the localisation technique used to identify the site of stimulation. In the experiments reported in **Chapters 2** and **4**, the l-pIPS was located on the basis on individual MRI scans, whereas in the experiment reported in **Chapter 3**, the l-pIPS was identified using the 10-20 system. Therefore, it is possible that the localisation of the target region was less accurate than if obtained from an MRI. However, another study (Finocchiaro et al, submitted) that used the 10-20 system replicated the results of Finocchiaro et al (2015), where individual MRIs were used.

Secondly, the experiments in **Chapters 2** and **4** used a spacer between the TMS coil and participant's scalp during the sham session. The experiment in **Chapter 3** on the other hand used a neutral region (Cz) in the sham condition. However, previous studies that have also used TMS on the parietal regions and found effects have also used Cz as a neutral region in the sham condition in previous studies (see Romero-Lauro, Cohen, Cecchetto, & Papagno, 2010).

Third, the differences in results may have been affected by the type of task. It has been seen previously that the slightest differences in stimuli may affect performance (Black et al., 1991). **Chapters 3** and **4** used a sentence-picture verification task, while **Chapter 2** used a judgement task. However, effects of rTMS were seen upon stimulating the l-pIPS when presented with both sentence-picture verification task (Finocchiaro et al., 2015) and with a judgement task (Finocchiaro et al., submitted). Therefore, I am sceptical of the role of task type in the current studies. Based on the results of previous literature, it seems unlikely that these slight deviations in protocol affected the results of the current experiments.

Finally, coil position across experiments could have affected stimulation site, and consequently the results. However, it is crucial to note that the coil orientation was consistent across all experiments and was monitored using neuronavigation. Moreover, in 3 of the 5 TMS studies

(Finocchiaro et al., 2015; Finocchiaro et al., submitted; Vercesi et al., submitted) that have used this orientation have shown an effect of TMS. Moreover, a marginal effect is also seen in one the sentence types in the fourth experiment with comparative sentences (see **Chapter 4**). Additionally, in the case of the experiment with Hindi sentences in **Chapter 3**, a null result was expected if the l-pIPS was important for reanalysis. The results of **Chapter 3** support this hypothesis. Therefore, while it is impossible to say with certainty whether the coil location and orientation was optimal, it seems unlikely that results were affected by coil positioning and orientation in the current experiments.

5.5. Final Comments and Conclusions

Taken together with the results of Finocchiaro et al (2015; submitted), the findings of the experiments reported here strongly indicate the involvement of the left pIPS in thematic reanalysis during sentence comprehension. More specifically, in the case of declarative sentences, results suggest that reanalysis requires the co-occurrence of passive voice with factors like reversibility and non-canonical word order. Findings also suggest that reanalysis may be affected by additional factors such as structure frequency, morphosyntactic features, and the presence of case markers. Studying languages rich in one or more of these features may help better understand their role in reanalysis.

Federico Fellini, an Italian filmmaker said, “a different language is a different vision of life”. In the same vein, findings from studies in different languages might help look at aspects of sentence comprehension in a different light.

References

Abuom, T. O., Shah, E., & Bastiaanse, R. (2013). Sentence comprehension in Swahili-English bilingual agrammatic speakers. *Clinical Linguistics & Phonetics*, 27, 355–370.

Amorapanth, P. X., Widick, P., & Chatterjee, A. (2010). The neural basis for spatial relations. *Journal of Cognitive Neuroscience*, *22*(8), 1739-1753.

Anjarningsih, H. Y., Haryadi-Soebadi, R. D., Gofir, A., & Bastiaanse, R. (2012). Characterising agrammatism in standard Indonesian. *Aphasiology*, 26, 757–784.

Ansell, B. J., & Flowers, C. R. (1982). Aphasic adults' use of heuristic and structural linguistic cues for sentence analysis. *Brain and Language*, *16*(1), 61-72.

Baldo J. V., & Dronkers N. F. (2006). The role of inferior parietal and inferior frontal cortex in working memory. *Neuropsychology,* 20, 529–538.

Baldo, J. V., & Dronkers, N. F. (2006). The role of inferior parietal and inferior frontal cortex in working memory. *Neuropsychology*, *20*(5), 529.

Barclay, J. R. (1973). The role of comprehension in remembering sentences. *Cognitive Psychology*, *4*(2), 229-254.

Bastiaanse, R., & Edwards, S. (2004). Word order and finiteness in Dutch and English Broca's and Wernicke's aphasia. *Brain and language*, *89*(1), 91-107.

Bastiaanse, R., & van Zonneveld, R. (2005). Sentence production with verbs of alternating transitivity in agrammatic Broca's aphasia. *Journal of Neurolinguistics*, *18*(1), 57-66.

Bastiaanse, R., & van Zonneveld, R. (2006). Comprehension of passives in Broca's aphasia. *Brain and Language*, *96*(2), 135-142.

Bates E., Wilson S. M., Saygin A. P., Dick F., Sereno M. I. & Knight R. T., et al. (2003). Voxel-based lesion–symptom mapping. *Nature Neuroscience*, 6, 448–450.

Baumann, O., & Mattingley, J. B. (2014). Dissociable roles of the hippocampus and parietal cortex in processing of coordinate and categorical spatial information. *Frontiers in Human Neuroscience*, *8*, 73.

Baumann, O., & Mattingley, J. B. (2014). Dissociable roles of the hippocampus and parietal cortex in processing of coordinate and categorical spatial information. *Frontiers in Human Neuroscience*, *8*, 73.

Beber, S., Capasso, R., Maffei, C., & Miceli, G. The neuroanatomy of morphosyntactic and thematic processes in sentence comprehension. *In preparation*

Ben-Shachar, M., Hendler, T., Kahn, I., Ben-Bashat, D., & Grodzinsky, Y. (2003). The neural reality of syntactic transformations: Evidence from functional magnetic resonance imaging. *Psychological Science*, *14*(5), 433-440.

Ben-Shachar, M., Palti, D., & Grodzinsky, Y. (2004). Neural correlates of syntactic movement: converging evidence from two fMRI experiments. *Neuroimage*, *21*(4), 1320-1336.

Bergmann, T. O., Karabanov, A., Hartwigsen, G., Thielscher, A., & Siebner, H. R. (2016). Combining non-invasive transcranial brain stimulation with neuroimaging and electrophysiology: current approaches and future perspectives. *Neuroimage*, *140*, 4-19.

Berndt, R. S., Mitchum, C. C., & Haendiges, A. N. (1996). Comprehension of reversible sentences in “agrammatism”: A meta-analysis. *Cognition*, *58*(3), 289-308.

Bertinetto, P. M., Burani, C., Laudanna, A., Marconi, L., Ratti, D., Rolando, C., & Thornton, A. M. (2005). Corpus e lessico di frequenza dell’italiano scritto (CoLFIS). *Scuola Normale Superiore di Pisa*.

Black, M., Nickels, L., & Byng, S. (1991). Patterns of sentence processing deficit: Processing simple sentences can be a complex matter. *Journal of Neurolinguistics*, *6*(2), 79-101.

Bolgün, M. A., & Mangla, A. (2017). A Contrastive Rhetoric Analysis of English and Hindi Editorials. *Journal of Pan-Pacific Association of Applied Linguistics*, *21*(2), 15-39.

Bonhage, C. E., Mueller, J. L., Friederici, A. D., & Fiebach, C. J. (2015). Combined eye tracking and fMRI reveals neural basis of linguistic predictions during sentence comprehension. *Cortex*, *68*, 33-47.

Bornkessel-Schlesewsky, I., Schlesewsky, M., & von Cramon, D. Y. (2009). Word order and Broca’s region: Evidence for a supra-syntactic perspective. *Brain and Language*, *111*(3), 125-139.

Bornkessel, I., & Schlesewsky, M. (2006). The extended argument dependency model: a neurocognitive approach to sentence comprehension across languages. *Psychological review*, *113*(4), 787.

Bornkessel, I., Zysset, S., Friederici, A. D., Von Cramon, D. Y., & Schlesewsky, M. (2005). Who did what to whom? The neural basis of argument hierarchies during language comprehension. *Neuroimage*, *26*(1), 221-233.

Brass, M., & Cramon, D. Y. V. (2004). Decomposing components of task preparation with functional magnetic resonance imaging. *Journal of Cognitive Neuroscience*, *16*(4), 609-620.

Bresnan J., 2000. Lexical-Functional Syntax. Blackwell, Oxford, UK

Brookshire, R. H., & Nicholas, L. E. (1980). Verification of active and passive sentences by aphasic and nonaphasic subjects. *Journal of Speech, Language, and Hearing Research*, *23*(4), 878-893.

Caplan D., Waters G., Kennedy D., Alpert, N., Makris N., DeDe G., et al. (2007). A study of syntactic processing in aphasia II: Neurological aspects. *Brain and Language*, 101, 151–177.

Caplan, D., & Futter, C. (1986). Assignment of thematic roles to nouns in sentence comprehension by an agrammatic patient. *Brain and Language*, *27*(1), 117-134.

Caplan, D., Alpert, N., & Waters, G. (1998). Effects of syntactic structure and propositional number on patterns of regional cerebral blood flow. *Journal of Cognitive Neuroscience*, *10*(4), 541-552.

Caplan, D., Hildebrandt, N., & Marshall, J. C. (1988). *Disorders of syntactic comprehension*. MIT Press.

Caramazza, A., & Miceli, G. (1991). Selective impairment of thematic role assignment in sentence processing. *Brain and Language*, *41*(3), 402-436.

Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language*, *3*(4), 572-582.

Carlson, K. (2009). How prosody influences sentence comprehension. *Language and Linguistics Compass*, *3*(5), 1188-1200.

Carreiras, M., Pattamadilok, C., Meseguer, E., Barber, H., & Devlin, J. T. (2012). Broca's area plays a causal role in morphosyntactic processing. *Neuropsychologia*, *50*(5), 816-820.

Chomsky N. (1965). Aspects of the Theory of Syntax. Cambridge, MA: MIT Press

Chomsky, N. (1981). Lectures on Government and Binding, Foris, Dordrecht. *ChomskyLectures on Government and Binding1981*.

Ciaramelli, E., Grady, C. L., & Moscovitch, M. (2008). Top-down and bottom-up attention to memory: a hypothesis (AtoM) on the role of the posterior parietal cortex in memory retrieval. *Neuropsychologia*, *46*(7), 1828-1851.

Clark, H. H., & Card, S. K. (1969). Role of semantics in remembering comparative sentences. *Journal of Experimental Psychology*, *82*(3), 545.

Clark, H. H., & Clark, E. V. (1968). Semantic distinctions and memory for complex sentences. *Quarterly Journal of Experimental Psychology*, *20*(2), 129-138.

Collette, F., Hogge, M., Salmon, E., & Van der Linden, M. (2006). Exploration of the neural substrates of executive functioning by functional neuroimaging. *Neuroscience*, *139*(1), 209-221.

Coslett, H. B., & Monsul, N. (1994). Reading with the right-hemisphere: Evidence from transcranial magnetic stimulation. *Brain and language*, *46*(2), 198-211.

Davison, A. (1980). Peculiar passives. *Language*, 42-66.

Davison, A. (1982). On the form and meaning of Hindi passive sentences. *Lingua*, *58*(1-2), 149-179.

Devlin, J. T., & Watkins, K. E. (2006). Stimulating language: insights from TMS. *Brain*, *130*(3), 610-622.

Devlin, J. T., & Watkins, K. E. (2008). Investigating language organization with TMS. *The Oxford Handbook of Transcranial Stimulation*, *479*, 499.

Dowty D. 1989. On the semantic content of the notion "Thematic Role". In G Chierchia, BH Partee & R Turner (Eds.), *Properties, Types and Meanings*, vol II, 69-130. Dordrecht: Kluwer.

Dowty D. 1991. Thematic Proto-Roles and argument selection. *Language*, 67: 547-619.

Dronkers N. F., Wilkins D. P., Van Valin R. D., Jr., Redfern B. B., & Jaeger J. J. (2004). Lesion analysis of the brain areas involved in language comprehension. *Cognition*, 92, 145–177.

Duman, T. Y., Altınok, N., Özgirgin, N., & Bastiaanse, R. (2011). Sentence comprehension in Turkish Broca's aphasia: An integration problem. *Aphasiology*, *25*(8), 908-926.

Duncan, J. (2006). EPS Mid-Career Award 2004: brain mechanisms of attention. *The Quarterly Journal of Experimental Psychology*, *59*(1), 2-27.

Duncan, J. (2010). The multiple-demand (MD) system of the primate brain: mental programs for intelligent behaviour. *Trends in Cognitive Sciences*, *14*(4), 172-179.

Duncan, J., & Owen, A. M. (2000). Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends in Neurosciences*, *23*(10), 475-483.

Fadiga, L., Craighero, L., Buccino, G., & Rizzolatti, G. (2002). Speech listening specifically modulates the excitability of tongue muscles: a TMS study. *European journal of Neuroscience*, *15*(2), 399-402.

Ferreira, F. (2003). The misinterpretation of noncanonical sentences. *Cognitive Psychology*, *47*(2), 164-203.

Fiebach, C. J., Friederici, A. D., Smith, E. E., & Swinney, D. (2007). Lateral inferotemporal cortex maintains Conceptual—Semantic representations in verbal working memory. *Journal of Cognitive Neuroscience*, *19*(12), 2035-2049.

Finocchiaro, C., Capasso, R., Cattaneo, L., Zuanazzi, A., & Miceli, G. (2015). Thematic role assignment in the posterior parietal cortex: A TMS study. *Neuropsychologia*, *77*, 223-232.

Finocchiaro, C., Cattaneo, L., & Miceli, G. (Submitted). Thematic reanalysis in the left posterior parietal sulcus: A TMS study. *Journal of Cognitive Neuroscience*.

Frazier, L., Carlson, K., & Clifton Jr, C. (2006). Prosodic phrasing is central to language comprehension. *Trends in Cognitive Sciences*, *10*(6), 244-249.

Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences*, *6*(2), 78-84.

Friederici, A. D. (2011). The brain basis of language processing: from structure to function. *Physiological Reviews*, *91*(4), 1357-1392.

Gahl, S., & Menn, L. (2016). Usage-based approaches to aphasia. *Aphasiology*, 1–17.

Gahl, S., Menn, L., Ramsberger, G., Jurafsky, D. S., Elder, E., Rewega, M., & Audrey, L. H. (2003). Syntactic frame and verb bias in aphasia: Plausibility judgments of undergoer-subject sentences. *Brain and Cognition*, 53, 223–228.

Gil, D. (2006). The acquisition of voice morphology in Jakarta Indonesian. In N. Gagarina & I.

Goldhahn, D., Eckart, T., & Quasthoff, U. (2012, May). Building Large Monolingual Dictionaries at the Leipzig Corpora Collection: From 100 to 200 Languages. In *LREC* (Vol. 29, pp. 31-43).

Goodglass, H., Kaplan, E., & Barresi, B. (2001). *The Assessment of Aphasia and Related Disorders*. Lippincott Williams & Wilkins.

Gourley, J. W., & Catlin, J. (1978). Children's comprehension of grammatical structures in context. *Journal of Psycholinguistic Research*, *7*(6), 419-434.

Grodzinsky, Y. (2000). The neurology of syntax: Language use without Broca's area. *Behavioral and Brain Sciences*, *23*(1), 1-21.

Gülzowm (Eds.), The acquisition of verbs and their grammar: The effect of particular languages (pp. pp. 201–227).

Haarmann, H. J., Davelaar, E. J., & Usher, M. (2003). Individual differences in semantic short-term memory capacity and reading comprehension. *Journal of Memory and Language*, *48*(2), 320-345.

Hagoort, P. (2005). On Broca, brain, and binding: a new framework. *Trends in Cognitive Sciences*, *9*(9), 416-423.

Hart Jr, J., & Gordon, B. (1990). Delineation of single-word semantic comprehension deficits in aphasia, with anatomical correlation. *Annals of Neurology: Official Journal of the American Neurological Association and the Child Neurology Society*, *27*(3), 226-231.

Hartwigsen, G. (2015). The neurophysiology of language: insights from non-invasive brain stimulation in the healthy human brain. *Brain and language*, *148*, 81-94.

Hedden, T., & Gabrieli, J. D. (2010). Shared and selective neural correlates of inhibition, facilitation, and shifting processes during executive control. *Neuroimage*, *51*(1), 421-431.

Henson R. N., Burgess N., & Frith C. D. (2000). Recoding, storage, rehearsal and grouping in verbal short-term memory: An fMRI study. *Neuropsychologia*, 38, 426–440.

Herwig, U., Satrapi, P., & Schönfeldt-Lecuona, C. (2003). Using the international 10-20 EEG system for positioning of transcranial magnetic stimulation. *Brain Topography*, *16*(2), 95-99.

Jap, B. A., Martinez-Ferreiro, S., & Bastiaanse, R. (2016). The effect of syntactic frequency on sentence comprehension in standard Indonesian Broca's aphasia. *Aphasiology*, *30*(11), 1325-1340.

Jonides, J., Schumacher, E. H., Smith, E. E., Koeppe, R. A., Awh, E., Reuter-Lorenz, P. A., ... & Willis, C. R. (1998). The role of parietal cortex in verbal working memory. *Journal of Neuroscience*, *18*(13), 5026-5034.

Junghare, I. Y. (1983, June). Markers of definiteness in Indo-Aryan. In *Annual Meeting of the Berkeley Linguistics Society* (Vol. 9, pp. 116-127).

Just, M. A., & Carpenter, P. A. (1971). Comprehension of negation with quantification. *Journal of Verbal Learning and Verbal Behavior*, *10*(3), 244-253.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: individual differences in working memory. *Psychological Review*, *99*(1), 122.

Kabdebon, C., Leroy, F., Simmonet, H., Perrot, M., Dubois, J., & Dehaene-Lambertz, G. (2014). Anatomical correlations of the international 10–20 sensor placement system in infants. *Neuroimage*, *99*, 342-356.

Kachru, Y. (1966). *An introduction to Hindi syntax*.Urbana, IL: University of Illinois.

Kachru, Y. (1970). Review of Peter Gaeffke, Untersuchungen zur Syntax des Hindi. *Language, 46*(4), 968-975.

Kachru, Y., & Nelson, C. L. (2006). *World Englishes in Asian Contexts* (Vol. 1). Hong Kong University Press.

Kaiser, E., & Trueswell, J. C. (2004). The role of discourse context in the processing of a flexible word-order language. *Cognition*, *94*(2), 113-147.

Keller T, Carpenter P, & Just M.A. (2001). The neural bases of sentence comprehension: an fMRI examination of syntactic and lexical processing. *Cereb. Cortex* 11, 223–37.

Kim, J., Koizumi, M., Ikuta, N., Fukumitsu, Y., Kimura, N., Iwata, K., ... & Kawashima, R. (2009). Scrambling effects on the processing of Japanese sentences: An fMRI study. *Journal of Neurolinguistics*, *22*(2), 151-166.

Kinno, R., Kawamura, M., Shioda, S., & Sakai, K. L. (2008). Neural correlates of noncanonical syntactic processing revealed by a picture-sentence matching task. *Human Brain Mapping*, *29*(9), 1015-1027.

Kinno, R., Kii, Y., Kurokawa, S., Owan, Y., Kasai, H., & Ono, K. (2017). Effects of word order and morphological information on japanese sentence comprehension in nonfluent/agrammatic variant of primary progressive aphasia. *Journal of Neurolinguistics*, *44*, 107-119.

Knecht, S., Flöel, A., Dräger, B., Breitenstein, C., Sommer, J., Henningsen, H., ... & Pascual-Leone, A. (2002). Degree of language lateralization determines susceptibility to unilateral brain lesions. *Nature Neuroscience*, *5*(7), 695.

Knoeferle, P., Crocker, M. W., Scheepers, C., & Pickering, M. J. (2005). The influence of the immediate visual context on incremental thematic role-assignment: Evidence from eye-movements in depicted events. *Cognition*, *95*(1), 95-127.

Koessler, L., Maillard, L., Benhadid, A., Vignal, J. P., Felblinger, J., Vespignani, H., & Braun, M. (2009). Automated cortical projection of EEG sensors: anatomical correlation via the international 10–10 system. *Neuroimage*, *46*(1), 64-72.

Kroczek, L. O., Gunter, T. C., Rysop, A. U., Friederici, A. D., & Hartwigsen, G. (2019). Contributions of left frontal and temporal cortex to sentence comprehension: Evidence from simultaneous TMS-EEG. *Cortex*.

Kropotov, J. D. (2016). *Functional neuromarkers for psychiatry: Applications for Diagnosis and Treatment*. Academic Press.

Kuhnke, P., Meyer, L., Friederici, A. D., & Hartwigsen, G. (2017). Left posterior inferior frontal gyrus is causally involved in reordering during sentence processing. *Neuroimage*, *148*, 254-263.

Lakoff, R. (1977). What you can do with words: Politeness, pragmatics and performatives. In *Proceedings of the Texas conference on performatives, presuppositions and implicatures* (pp. 79-106).

Lauro, L. J. R., Reis, J., Cohen, L. G., Cecchetto, C., & Papagno, C. (2010). A case for the involvement of phonological loop in sentence comprehension. *Neuropsychologia*, *48*(14), 4003-4011.

Lauro, L. J. R., Reis, J., Cohen, L. G., Cecchetto, C., & Papagno, C. (2010). A case for the involvement of phonological loop in sentence comprehension. *Neuropsychologia*, *48*(14), 4003-4011.

Love T., Swinney D., Walenski M., & Zurif E. (2008). How left inferior frontal cortex participates in syntactic processing: Evidence from aphasia. *Brain and Language*, 107, 203–219.

Luzzatti, C., Toraldo, A., Guasti, M. T., Ghirardi, G., Lorenzi, L., & Guarnaschelli, C. (2001). Comprehension of reversible active and passive sentences in agrammatism. *Aphasiology*, *15*(5), 419-441.

MacDonald, M. C., & Sussman, R. S. (2009). Sentence comprehension. In L. R. Squire (Ed), *Encyclopaedia of Neuroscience* (pp. 618-686). Academic Press.

Mack, J., Meltzer-Asscher, A., Barbieri, E., & Thompson, C. (2013). Neural correlates of processing passive sentences. *Brain Sciences*, *3*(3), 1198-1214.

MacWhinney, B., Bates, E., & Kliegl, R. (1984). Cue validity and sentence interpretation in English, German and Italian. *Journal of Verbal Learning and Verbal Behavior*, 23(2), 127–150.

MacWhinney, B., Pleh, C., & Bates, E. (1985). The development of sentence interpretation in Hungarian. *Cognitive Psychology*, 17, 178–209.

Magier, D. (1987). The transitivity prototype: evidence from Hindi. *Word*, *38*(3), 187-199.

Magnusdottir, S., Fillmore, P., Den Ouden, D. B., Hjaltason, H., Rorden, C., Kjartansson, O., ... & Fridriksson, J. (2013). Damage to left anterior temporal cortex predicts impairment of complex syntactic processing: A lesion-symptom mapping study. *Human brain mapping*, *34*(10), 2715-2723.

Martin A., Schurz M., Kronbichler M., & Richlan F. (2015). Reading in the brain of children and adults: A meta-analysis of 40 functional magnetic resonance imaging studies. *Human Brain Mapping*, 36, 1963–1981.

Martin R.C., & Blossom-Stach C. (1986). Evidence of syntactic deficits in a fluent aphasic. *Brain and Language*, 28, 196-234.

Martin, P. I., Naeser, M. A., Theoret, H., Tormos, J. M., Nicholas, M., Kurland, J., ... & Pascual-Leone, A. (2004, May). Transcranial magnetic stimulation as a complementary treatment for aphasia. In *Seminars in speech and language* (Vol. 25, No. 02, pp. 181-191). Copyright© 2004 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA..

Martin, R. C., & He, T. (2004). Semantic short-term memory and its role in sentence processing: A replication. *Brain and Language*, *89*(1), 76-82.

Masica, C. (1982). Identified object marking in Hindi and other languages. *Topics in Hindi Linguistics*, *2*, 16-50.

Meltzer-Asscher, A., Schuchard, J., den Ouden, D. B., & Thompson, C. K. (2013). The neural substrates of complex argument structure representations: Processing “alternating transitivity” verbs. *Language and Cognitive Processes*, *28*(8), 1154-1168.

Merabet, L. B., & Pascual-Leone, A. (2009). Transcranial Magnetic Stimulation.

Meyer A.M., Mack J.E., Thompson C.K., 2012. Tracking passive sentence comprehension in agrammatic aphasia. *J. Neurolinguist* 25, 31–43.

Meyer L. & Friederici A.D. (2015). Neural systems underlying the processing of complex sentences. In G. Hickok & S. Small (Eds.), *Neurobiology of Language* (pp. 597–606). Amsterdam (The Netherlands) and Boston (Massachusetts): *Academic Press*.

Meyer, A. M., Mack, J. E., & Thompson, C. K. (2012). Tracking passive sentence comprehension in agrammatic aphasia. *Journal of Neurolinguistics*, *25*(1), 31-43.

Mirman D. & Graziano K.M. (2012a) Damage to temporo-parietal cortex decreases incidental activation of thematic relations during spoken word comprehension. *Neuropsychologia* 50, 1990 –1997.

Mohanan, T. (1994). *Argument structure in Hindi*. Center for the Study of Language (CSLI).

Montaut, A. (2018). The rise of differential object marking in Hindi and related languages. *Diachrony of differential argument marking*, *19*, 281.

Naeser, M. A., Martin, P. I., Nicholas, M., Baker, E. H., Seekins, H., Kobayashi, M., ... & Doron, K. W. (2005). Improved picture naming in chronic aphasia after TMS to part of right Broca’s area: an open-protocol study. *Brain and Language*, *93*(1), 95-105.

Naeser, M. A., Martin, P. I., Nicholas, M., Baker, E. H., Seekins, H., Helm-Estabrooks, N., ... & Maria Tormos, J. (2005). Improved naming after TMS treatments in a chronic, global aphasia patient–case report. *Neurocase*, *11*(3), 182-193.

Newman, S. D., Just, M. A., Keller, T. A., Roth, J., & Carpenter, P. A. (2003). Differential effects of syntactic and semantic processing on the subregions of Broca's area. *Cognitive Brain Research*, *16*(2), 297-307.

Novais-Santos, S., Gee, J., Shah, M., Troiani, V., Work, M., & Grossman, M. (2007). Resolving sentence ambiguity with planning and working memory resources: Evidence from fMRI. *Neuroimage*, *37*(1), 361-378.

Okamoto, M., Dan, H., Sakamoto, K., Takeo, K., Shimizu, K., Kohno, S., Oda, I., Isobe, S., Suzuki, T., Kohyama, K., Dan, I., 2004. Three dimensional probabilistic anatomical cranio–cerebral correlation via the international 10–20 system oriented for transcranial functional brain mapping. *Neuroimage* 21, 99–111

Olson, D. R., & Filby, N. (1972). On the comprehension of active and passive sentences. *Cognitive Psychology*, *3*(3), 361-381.

Palti, D., Ben-Shachar, M., Hendler, T., & Hadar, U. (2007). The cortical correlates of grammatical category differences: An fMRI study of nouns and verbs. *Human Brain Mapping*, *28*, 303-314.

Pandharipande, R. (1979). Passive as an optional rule in Hindi, Marathi, and Nepali. *South Asian Languages Analysis*, *1*, 89-106.

Pandharipande, R. (1981). Interface of Lexicon and Grammar: Some Problems in Hindi Grammar in Dimensions of South Asian Linguistics. *Studies in the Linguistic Sciences Urbana, Ill*., *11*(2), 77-100.

Papagno, C., & Cecchetto, C. (2019). Is STM involved in sentence comprehension?. *Cortex*, *112*, 80-90.

Papagno, C., Cecchetto, C., Reati, F., & Bello, L. (2007). Processing of syntactically complex sentences relies on verbal short-term memory: Evidence from a short-term memory patient. *Cognitive Neuropsychology*, *24*(3), 292-311.

Pascual-Leone, A., Walsh, V., & Rothwell, J. (2000). Transcranial magnetic stimulation in cognitive neuroscience–virtual lesion, chronometry, and functional connectivity. *Current Opinion in Neurobiology*, *10*(2), 232-237.

Paus, T. (2005). Inferring causality in brain images: a perturbation approach. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1457), 1109-1114.

Pickering, M. J., & Garrod, S. (2007). Do people use language production to make predictions during comprehension?. *Trends in Cognitive Sciences*, *11*(3), 105-110.

Pollard C., & Sag I.A., (1994). Head-Driven Phrase Structure Grammar. *The University of Chicago Press*, Chicago, IL, USA.

Postman, W. A. (2004). Processing of complex sentences in a case of aphasia in Indonesian: Thematic vs. linear strategies. *Journal of Neurolinguistics*, 17, 455–489.

Prasithrathsint, A. (1988). Change in the passive constructions in Standard Thai from 1802 to 1982. *Language Sciences*, *10*(2), 363-393.

Prat, C. S., Keller, T. A., & Just, M. A. (2007). Individual differences in sentence comprehension: a functional magnetic resonance imaging investigation of syntactic and lexical processing demands. *Journal of Cognitive Neuroscience*, *19*(12), 1950-1963.

Pulvermuller, F., Hauk, O., Nikulin, V. V., & Ilmoniemi, R. J. (2005). Functional links between motor and language systems. In *European Journal of Neuroscience*.

Randriamasimanana, C. (1999). The Malayo-Polynesian Origins of Malagasy. *From Neanderthal to Easter Island, Association for the History of Language*, 26-43.

Richardson, F. M., Thomas, M. S., & Price, C. J. (2010). Neuronal activation for semantically reversible sentences. *Journal of Cognitive Neuroscience*, *22*(6), 1283-1298.

Rodd J. M., Vitello S., Woollams A.M., & Adank P. (2015). Localising semantic and syntactic processing in spoken and written language comprehension: An activation likelihood estimation meta-analysis. *Brain and Language*, 141, 89–102.

Rogalsky C., LaCroix A.N., Chen K.H. & Anderson S.W. (2018). The Neurobiology of agrammatic sentence comprehension: a lesion study. *Journal of Cognitive Neuroscience* 30, 234-255.

Rogalsky, C., Matchin, W., & Hickok, G. (2008). Broca's area, sentence comprehension, and working memory: an fMRI study. *Frontiers in Human Neuroscience*, *2*, 14.

Romero Lauro L.J., Reis J., Cohen L.G., Cecchetto C., Papagno C., (2010). A case for the involvement of phonological loop in sentence comprehension. *Neuropsychologia* 48 (14), 4003–4011.

Romero, L., Walsh, V., & Papagno, C. (2006). The neural correlates of phonological short-term memory: a repetitive transcranial magnetic stimulation study. *Journal of Cognitive Neuroscience*, *18*(7), 1147-1155.

Rossi, S., Gugler, M. F., Hahne, A., & Friederici, A. D. (2005). When word category information encounters morphosyntax: An ERP study. *Neuroscience Letters*, *384*(3), 228-233.

Rossi, S., Hallett, M., Rossini, P. M., Pascual-Leone, A., & Safety of TMS Consensus Group. (2009). Safety, ethical considerations, and application guidelines for the use of transcranial magnetic stimulation in clinical practice and research. *Clinical Neurophysiology*, *120*(12), 2008-2039.

Rotenberg, A., Horvath, J. C., & Pascual-Leone, A. (2014). Neuromethods: Transcranial Magnetic Stimulation. *Springer, New York, NY. doi*, *10*, 978-1.

Sack, A. T. (2006). Transcranial magnetic stimulation, causal structure–function mapping and networks of functional relevance. *Current Opinion in Neurobiology*, *16*(5), 593-599.

Sakai, K. L., Noguchi, Y., Takeuchi, T., & Watanabe, E. (2002). Selective priming of syntactic processing by event-related transcranial magnetic stimulation of Broca's area. *Neuron*, *35*(6), 1177-1182.

Saksena, A. (1980). The affected agent. *Language*, 812-826.

Schafer, A. J. (1997). *Prosodic parsing: The role of prosody in sentence comprehension* (Doctoral dissertation, University of Massachusetts at Amherst).

Schnitzer, M. L. (2014). *The pragmatic basis of aphasia: a neurolinguistic study of morphosyntax among bilinguals*. Psychology Press.

Schwartz, M. F., Linebarger, M. C., Saffran, E. M., & Pate, D. S. (1987). Syntactic transparency and sentence interpretation in aphasia. *Language and Cognitive Processes*, *2*(2), 85-113.

Schwartz, M. F., Saffran, E. M., & Marin, O. S. (1980). The word order problem in agrammatism: I. Comprehension. *Brain and language*, *10*(2), 249-262.

Shapiro, M. C. (1989). *A primer of modern standard Hindi*. Motilal Banarsidass Publishers. 135-137

Sherman, M. A. (1976). Adjectival negation and the comprehension of multiply negated sentences. *Journal of Verbal Learning and Verbal Behavior*, *15*(2), 143-157.

Shetreet, E., Palti, D., Friedmann, N., & Hadar, U. (2006). Cortical representation of verb processing in sentence comprehension: Number of complements, subcategorization, and thematic frames. *Cerebral Cortex*, *17*(8), 1958-1969.

Siebner, H. R., Hartwigsen, G., Kassuba, T., & Rothwell, J. C. (2009). How does transcranial magnetic stimulation modify neuronal activity in the brain? Implications for studies of cognition. *Cortex*, *45*(9), 1035-1042.

Siebner, H., & Rothwell, J. (2003). Transcranial magnetic stimulation: new insights into representational cortical plasticity. *Experimental Brain Research*, *148*(1), 1-16.

Sliwinska, M. W., Vitello, S., & Devlin, J. T. (2014). Transcranial magnetic stimulation for investigating causal brain-behavioral relationships and their time course. *JoVE (Journal of Visualized Experiments)*, (89), e51735.

Slobin, D. I., & Bever, T. G. (1982). Children use canonical sentence schemas: a crosslinguistic study of word order and inflections. *Cognition*, 12, 229–265.

Smith, S., & Bates, E. (1987). Accessibility of case and gender contrasts for agent-object assignment in Broca's aphasics and fluent anomics. *Brain and Language*, 30(1), 8–32.

Sommer, M., Ciocca, M., Chieffo, R., Hammond, P., Neef, A., Paulus, W., ... & Hannah, R. (2018). TMS of primary motor cortex with a biphasic pulse activates two independent sets of excitable neurones. *Brain Stimulation*, *11*(3), 558-565.

Srivastava, R. N., & Pandit, I. (1988). The pragmatic basis of syntactic structures and the politeness hierarchy in Hindi. *Journal of Pragmatics*, *12*(2), 185-205.

Sundara, M., Namasivayam, A. K., & Chen, R. (2001). Observation–execution matching system for speech: a magnetic stimulation study. *Neuroreport*, *12*(7), 1341-1344

Talmy, L. (1985). Lexicalization patterns: Semantic structure in lexical forms. *Language Typology and Syntactic Description*, *3*(99), 36-149.

Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., ... & Perani, D. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience*, *17*(2), 273-281.

Thiel, A., Hartmann, A., Rubi-Fessen, I., Anglade, C., Kracht, L., Weiduschat, N., ... & Heiss, W. D. (2013). Effects of noninvasive brain stimulation on language networks and recovery in early poststroke aphasia. *Stroke*, *44*(8), 2240-2246.

Thompson C. K., & Choy J. J. (2009). Pronominal resolution and gap filling in agrammatic aphasia: Evidence from eye movements. *Journal of Psycholinguistic Research*, 38, 255–283.

Thompson, C. K., & Meltzer-Asscher, A. (2014). Neurocognitive mechanisms of verb argument structure processing. *Structuring the argument*, 141-168.

Thompson, C. K., Bonakdarpour, B., & Fix, S. F. (2010). Neural mechanisms of verb argument structure processing in agrammatic aphasic and healthy age-matched listeners. *Journal of Cognitive Neuroscience*, *22*(9), 1993-2011.

Thompson, C. K., Bonakdarpour, B., Fix, S. C., Blumenfeld, H. K., Parrish, T. B., Gitelman, D. R., & Mesulam, M. M. (2007). Neural correlates of verb argument structure processing. *Journal of Cognitive Neuroscience*, *19*(11), 1753-1767.

Thompson, C. K., Riley, E. A., den Ouden, D. B., Meltzer-Asscher, A., & Lukic, S. (2013). Training verb argument structure production in agrammatic aphasia: Behavioral and neural recovery patterns. *Cortex*, *49*(9), 2358-2376.

Thothathiri, M., Kimberg, D. Y., & Schwartz, M. F. (2012). The neural basis of reversible sentence comprehension: evidence from voxel-based lesion symptom mapping in aphasia. *Journal of Cognitive Neuroscience*, *24*(1), 212-222.

Tirkkonen-Condit, S., & Lieflander-Koistinen, L. (1989). Argumentation in Finnish versus English and German editorials. *Text, interpretation, argumentation*, 173-181.

Tune, S., Schlesewsky, M., Nagels, A., Small, S. L., & Bornkessel-Schlesewsky, I. (2016). Sentence understanding depends on contextual use of semantic and real-world knowledge. *NeuroImage*, *136*, 10-25.

Turner, E. A., & Rommetveit, R. (1967). Experimental manipulation of the production of active and passive voice in children. *Language and Speech*, *10*(3), 169-180.

Uddén, J., Folia, V., Forkstam, C., Ingvar, M., Fernández, G., Overeem, S., ... & Petersson, K. M. (2008). The inferior frontal cortex in artificial syntax processing: An rTMS study. *Brain Research*, *1224*, 69-78.

Vercesi L., Sabnis P., Finocchiaro C., Cattaneo L., Tonolli E., & Miceli G. (Submitted). The role of the l-IPS in the comprehension of reversible and irreversible sentences: an rTMS study. *Neuropsychologia*.

Wager, T. D., Jonides, J., & Reading, S. (2004). Neuroimaging studies of shifting attention: a meta-analysis. *Neuroimage*, *22*(4), 1679-1693.

Walenski M., Europa E., Caplan D. & Thompson C.K. (2019). Neural networks for sentence comprehension and production: An ALE-based meta-analysis of neuroimaging studies. *Hum Brain Mapp*, 39, 1-30.

Walsh, V., & Cowey, A. (2000). Transcranial magnetic stimulation and cognitive neuroscience. *Nature Reviews Neuroscience*, *1*(1), 73.

Wang J., Cherkassky V.L., Yang Y., Chang K.K., Vargas R., Diana N., & Just M.A. (2016): Identifying thematic roles from neural representations measured by functional magnetic resonance imaging. *Cognitive Neuropsychology* 1–8.

Warrington, E. K. (1975). The selective impairment of semantic memory. *The Quarterly Journal of Experimental Psychology*, *27*(4), 635-657.

Wassenaar, M., & Hagoort, P. (2007). Thematic role assignment in patients with Broca's aphasia: Sentence–picture matching electrified. *Neuropsychologia*, *45*(4), 716-740.

Wassermann, E., Epstein, C., Ziemann, U., Walsh, V., Paus, T., & Lisanby, S. (Eds.). (2008). *Oxford Handbook of Transcranial Stimulation*. Oxford University Press.

Watkins, K. E., Strafella, A. P., & Paus, T. (2003). Seeing and hearing speech excites the motor system involved in speech production. *Neuropsychologia*, *41*(8), 989-994.

Whitney, C., Kirk, M., O'Sullivan, J., Lambon Ralph, M. A., & Jefferies, E. (2012). Executive semantic processing is underpinned by a large-scale neural network: revealing the contribution of left prefrontal, posterior temporal, and parietal cortex to controlled retrieval and selection using TMS. *Journal of Cognitive Neuroscience*, *24*(1), 133-147.

Winhuisen, L., Thiel, A., Schumacher, B., Kessler, J., Rudolf, J., Haupt, W. F., & Heiss, W. D. (2005). Role of the contralateral inferior frontal gyrus in recovery of language function in poststroke aphasia: a combined repetitive transcranial magnetic stimulation and positron emission tomography study. *Stroke*, *36*(8), 1759-1763.

Wischnewski, M., & Schutter, D. J. (2015). Efficacy and time course of theta burst stimulation in healthy humans. *Brain stimulation*, *8*(4), 685-692.

Wu D. H., Waller S. & Chatterjee A. (2007) The functional neuroanatomy of thematic role and locative relational knowledge. *Journal of Cognitive Neuroscience* 19, 1542–1555.

Yano, M., Yasunaga, D., & Koizumi, M. (2017). Event-related brain indices of gap-filling processing in Kaqchikel. *Event-Related Potential (ERP): Methods, Outcomes and Research Insights. NOVA.*

APPENDIX A

CHAPTER 2 – PILOT SUMMARY

In the experiment, participants were presented with reversible and irreversible active and passive voice sentences. The experiment required participants to perform two tasks. In one they had to identify the agent of the active/passive sentence, in the other the theme of the active/passive sentence. In order to ensure that both tasks were of similar difficulty levels, two separate pilots were conducted – one for each task. We found no differences between participant performance on the two tasks. Following this, both tasks were incorporated into the main experiment.

Examples of the stimuli sentences are given below. All the stimuli sentences are presented in Appendix B.

Irreversible Active (IA)

Il vigile ha fermato il camion

il ˈvidʒilɛ$_{[SG.M]}$ a ferˈmato$_{[3.SG.PRS.PASS]}$ il ˈkamjon$_{[SG.M]}$

The policeman stopped the truck.

Irreversible Passive (IP)

Il camion è stato fermato dal vigile

il ˈkamjon$_{[SG.M]}$ ɛ ˈstato ferˈmato$_{[3.SG.PRS.PASS]}$ dal ˈvidʒilɛ$_{[SG.M]}$

The truck was stopped by the policeman

Reversible Active (RA)

Il vigile ha fermato il direttore

il ˈvidʒilɛ$_{[SG.M]}$ a ferˈmato$_{[3.SG.PRS.PASS]}$ il diretˈtore$_{[SG.M]}$

The policeman stopped the director.

Reversible Passive (RP)

Il direttore è stato fermato dal vigile

il diretˈtore$_{[SG.M]}$ ɛ ˈstato ferˈmato$_{[3.SG.PRS.PASS]}$ dal ˈvidʒilɛ$_{[SG.M]}$

The director was stopped by the policeman.

APPENDIX B

CHAPTER 2 – STIMULI

IA – Irreversible Active Sentence
IP – Irreversible Passive Sentence
RA – Reversible Active Sentence
RP – Reversible Passive Sentence

1.
IA – Il ballerino ha ricordato la canzone
The dancer remembered the song.
IP – La canzone è stata ricordata dal ballerina
The song was remembered by the dancer.
RA – Il ballerino ha ricordato il ciclista
The dancer remembered the cyclist.
RP – Il ciclista è stato ricordato dal ballerina
The cyclist was remembered by the dancer.

2.
IA – Il bambino ha sfiorato lo sgabello
The child touched the stool.
IP – Lo sgabello è stato sfiorato dal bambino
The stool was touched by the child.
RA – Il bambino ha sfiorato lo psicologo
The child touched the psychologist.
RP – Lo psicologo è stato sfiorato dal bambino
The psychologist was touched by the child.

3.
IA – Il cacciatore ha fotografato la montagna
The hunter photographed the mountain.
IP – La montagna è stata fotografata dal cacciatore
The mountain was photographed by the hunter.
RA – Il cacciatore ha fotografato il cuoco
The hunter photographed the cook.
RP – Il cuoco è stato fotografato dal cacciatore
The cook was photographed by the hunter.

4.
IA – Il calciatore ha colpito il sacco
The footballer hit the bag.
IP – Il sacco è stato colpito dal calciatore
The bag was hit by the footballer.
RA – Il calciatore ha colpito il macellaio
The footballer hit the butcher.
RP – Il macellaio è stato colpito dal calciatore
The butcher was hit by the player.

5.
IA – Il chirurgo ha aspettato il pacco
The surgeon waited for the package.
IP – Il pacchetto è stato atteso dal chirurgo
The package was awaited by the surgeon.
RA – Il chirurgo ha aspettato la segretaria
The surgeon waited for the secretary.
RP – Il segretario è stato atteso dal chirurgo
The secretary was awaited by the surgeon.

6.
IA – Il contabile ha menzionato il ristorante
The accountant mentioned the restaurant.

IP – Il ristorante è stato menzionato dal contabile

The restaurant was mentioned by the accountant.

RA – Il contabile ha menzionato il produttore

The accountant mentioned the producer.

RP – Il produttore è stato menzionato dal contabile

The producer was mentioned by the accountant.

7.

IA – Il contadino ha descritto il trattore

The farmer described the tractor.

IP – Il trattore è stato descritto dal contadino

The tractor was described by the farmer.

RA – Il contadino ha descritto l'attore

The farmer described the actor.

RP – L'attore è stato descritto dal contadino

The actor was described by the farmer.

8.

IA – Il dentista ha evitato il treno

The dentist avoided the train.

IP – Il treno è stato evitato dal dentista

The train was avoided by the dentist

RA – Il dentista ha evitato l'uomo

The dentist avoided the man.

RP – L'uomo è stato evitato dal dentista

The man was avoided by the dentist.

9.

IA – Il fioraio ha spinto l'altalena

The florist pushed the swing.

IP – L'altalena è stata spinta dal fioraio

The swing was pushed by the florist

RA – Il fioraio ha spinto il banchiere

The florist pushed the banker.

RP – Il banchiere è stato spinto dal fioraio

The banker was pushed by the florist.

10.

IA – Il bidello ha registrato il corteo

The janitor recorded the procession.

IP – Il corteo è stato registrato dal bidello

The procession was recorded by the janitor.

RA – Il bidello ha registrato il falegname

The janitor recorded the carpenter.

RP – Il falegname è stato registrato dal bidello

The carpenter was recorded by the janitor.

11.

IA – Il nuotatore ha guardato l'edificio

The swimmer looked at the building.

IP – L'edificio è stato guardato dal nuotatore

The building was looked at by the swimmer.

RA – Il nuotatore ha guardato il cassiere

The swimmer looked at the cashier.

RP – Il cassiere è stato guardato dal nuotatore

The cashier was looked at by the swimmer.

12.

IA – Il politico ha osservato la scultura

The politician observed the sculpture.

IP – La scultura è stata osservata dal politico

The sculpture was observed by the politician.

RA – Il politico ha osservato il pilota

The politician observed the pilot.

RP – Il pilota è stato osservato dal politico

The pilot was observed by the politician

13.

IA – Il poliziotto ha notato l'albero

The policeman noticed the tree.

IP – L'albero è stato notato dal poliziotto

The tree was spotted by the policeman.

RA – Il poliziotto ha notato il pittore

The policeman noticed the painter.

RP – Il pittore è stato notato dal poliziotto

The painter was noticed by the policeman.

14.

IA – Il postino ha dimenticato la lettera

The postman has forgotten the letter.

IP – La lettera è stata dimenticata dal postino

The letter was forgotten by the postman.

RA – Il postino ha dimenticato il poeta

The postman has forgotten the poet.

RP – Il poeta è stato dimenticato dal postino

The poet has been forgotten by the postman.

15.

IA – Il sarto ha nascosto il Tesoro

The tailor has hidden the treasure.

IP – Il tesoro è stato nascosto dal sarto

The treasure was hidden by the tailor.

RA – Il sarto ha nascosto il cliente

The tailor has hidden the client.

RP – Il giardiniere è stato nascosto dal sarto

The gardener was hidden by the tailor.

16.

IA – Il soldato ha salutato la nave

The soldier greeted the ship.

IP – La nave è stata salutata dal soldato

The ship was greeted by the soldier.

RA – Il soldato ha salutato il sovrano

The soldier greeted the sovreign.

RP – Il sovrano è stato salutato dal soldato

The sovereign was greeted by the soldier.

17.

IA – Il vigile ha fermato il camion

The policeman stopped the truck.

IP – Il camion è stato fermato dal vigile

The truck was stopped by the traffic warden.

RA – Il vigile ha fermato il direttore

The policeman stopped the director.

RP – Il direttore è stato fermato dal vigile

The manager was stopped by the policeman.

18.

IA – L'autista ha ammirato la bicicletta

The driver admired the bicycle.

IP – La bicicletta è stata ammirata dall'autista

The bicycle was admired by the driver.

RA – L'autista ha ammirato l'architetto

The driver admired the architect.

RP – L'architetto è stato ammirato dall'autista

The architect was admired by the driver.

19.

IA – L'avvocato ha applaudito lo spettacolo

The lawyer applauded the show.

IP – Lo spettacolo è stato applaudito dall'avvocato

The show was applauded by the lawyer.

RA – L'avvocato ha applaudito il cantante

The lawyer applauded the singer.

RP – Il cantante è stato applaudito dall'avvocato

The singer was applauded by the lawyer.

20.

IA – L'idraulico ha afferrato la chiave

The plumber grabbed the key.

IP – La chiave è stata afferrata dall'idraulico

The key was grabbed by the plumber.

RA – L'idraulico ha afferrato il pompiere

The plumber grabbed the fireman.

RP – Il pompiere è stato afferrato dall'idraulico

The fireman was grabbed by the plumber.

21.

IA – L'impiegato ha fotografato la statua

The clerk photographed the statue.

IP – La statua è stata fotografata dall'impiegato

The statue was photographed by the clerk.

RA – L'impiegato ha fotografato il prete

The clerk photographed the priest.

RP – Il prete è stato fotografato dall'impiegato

The priest was photographed by the clerk.

22.

IA – L'ingegnere ha disegnato il castello

The engineer designed the castle.

IP – Il castello è stato disegnato dall'ingegnere

The castle was designed by the engineer.

RA – L'ingegnere ha disegnato il medico

The engineer designed the doctor.

RP – Il medico è stato disegnato dall'ingegnere

The doctor was designed by the engineer.

23.

IA – L'insegnante ha criticato il tema

The teacher criticised the topic.

IP – Il tema è stato criticato dall'insegnante

The theme was criticised by the teacher.

RA – L'insegnante ha criticato l'attrice

The teacher criticised the actress.

RP – L'attrice è stata criticata dall'insegnante

The actress was criticised by the teacher.

24.

IA – L'investigatore ha visto l'auto

The investigator saw the car.

IP – L'auto è stata vista dall'investigatore

The car was seen by the investigator.

RA – L'investigatore ha visto il ladro

The investigator saw the thief.

RP – Il ladro è stato visto dall'investigatore

The thief was seen by the investigator.

25.

IA – La bambina ha baciato la bambola

The girl kissed the doll.

IP – La bambola è stata baciata dalla ragazza

The doll was kissed by the girl.

RA – La bambina ha baciato la poliziotta

The little girl kissed the cop.

RP – La poliziotta è stata baciata dalla ragazza

The policewoman was kissed by the girl.

26.

IA – La cameriera ha trovato la borsa

The maid found the bag.

IP – La borsa è stata trovata dalla cameriera

The bag was found by the maid.

RA – La cameriera ha trovato la bambina

The waitress found the child.

RP – La bambina è stata trovata dalla cameriera

The child was found by the maid.

27.

IA – La donna ha tirato il carrello

The woman pulled the cart.

IP – Il carrello è stato tirato dalla donna

The cart was pulled by the woman.

RA – La donna ha tirato il violinista

The woman has pulled the violinist.

RP – Il violinista è stato tirato dalla donna

The violinist was pulled by the woman.

28.

IA – Lo scienziato ha visitato la monumenta

The scientist visited the monument.

IP – La monumenta è stata visitata dallo scienziato

The monument was visited by the scientist.

RA – Lo scienziato ha visitato il giudice

The scientist visited the judge.

RP – Il giudice è stato visitato dallo scienziato

The judge was visited by the scientist.

29.

IA – Lo scrittore ha abbracciato il cuscino

The writer hugged the pillow.

IP – Il cuscino è stato abbracciato dallo scrittore

The pillow was hugged by the writer.

RA – Lo scrittore ha abbracciato il giornalista

The writer has hugged the journalist.

RP – Il giornalista è stato abbracciato dallo scrittore

The journalist was huggedby the writer.

30.

IA – Lo studente ha elogiato la presentazione

The student praised the presentation.

IP – La presentazione è stata elogiata dallo student

The presentation was praised by the student.

RA – Lo studente ha elogiato il professore

The student praised the professor.

RP – Il professore è stato elogiato dallo student

The professor was praised by the student.

APPENDIX C

Passive Sentences in Hindi

1.1 Language Structure in Hindi

Hindi differs from English on two main accounts that are relevant to the current study. Firstly, while English follows an SVO canonical order, Hindi uses a subject-object-verb (SOV) template. Secondly, Hindi has a relatively free word order (Kachru, 2006). For comparison, if English is used as an example of a fixed word order language, and Warlpiri, a language form Central Australia as a free word order language, Hindi lies in between in terms of word order rigidity. The examples below give us a better understanding of this. They all correspond to the English sentence *Radhika sold the book to Rashmi*.

e.g. 2a) *radhika*$_{(SBJ)}$ *ne kitab rashmi*$_{(OBJ)}$ *ko bechi*.

radhika book rashmi sold.

2b) *radhika*$_{(SBJ)}$ *ne rashmi*$_{(OBJ)}$ *ko kitaab bechi*.

radhika rashmi book sold.

2c) *kitaab Rashmi*$_{(OBJ)}$ *ko radhika*$_{(SBJ)}$ *ne bechi*.

book rashmi radhika sold.

All three versions of the sentence given in the examples above are grammatically correct and acceptable in Hindi. However, only 2a follows the canonical (SOV) order. In examples 2b and 2c, when the object is displaced from its canonical position to immediately precede the verb, the object becomes more definite and interpretation is restricted (Mohanan, 1994). The examples also illustrate the legality of scrambling in Hindi, albeit with restrictions. More specifically, Hindi allows scrambling of finite clauses and of non-finite clauses with respect to the matrix clause. This is illustrated better in the examples below where elements of the non-finite clauses are highlighted in bold face. The English translation of these sentences would be: *Shashi told Raghav to keep Neha's box in the room.*

2e) *shashi-ne raghav-se* ***neha-ka baksa kamre mein rakhne ko*** *kaha.*

shashi raghav neha box room in keep told.

2f) *raghav-se* ***neha-ka baksa*** *shashi-ne* ***kamre mein rakhne ko*** *kaha.*

raghav neha box shashi room in keep told.

2g) *raghav-se* ***neha-ka baksa kamre mein*** *shashi-ne* ***rakhne ko*** *kaha.*

raghav neha box room in shashi keep told.

2h) *shashi-ne* ***neha-ka baksa*** *raghav-se* ***kamre mein rakhne ko*** *kaha.*

shashi neha box raghav room in keep told.

It is important to note that only non-finite clauses may be scrambled with respect to a matrix clause; while other constituents may not. For example, parts of a noun phrase cannot be scrambled. Such sentences would be considered illegal in Hindi. (Mohanan, 1994). This is illustrated in the examples below where sentences 2j and 2k are ungrammatical. Parts of the constituent are given in bold face in the examples below. Sentences 2i-2k can be translated to *Neha bought Shiv's old book from Pooja* in English.

2i) *neha-ne pooja-se* ***shiv-ki puranii kitab*** *kharidi.*

Neha pooja Shiv old book bought.

2j) *neha-ne* ***shiv-ki*** *pooja-se* ***puranii kitab*** *kharidi.* *

neha shiv pooja old book bought.

2k) *pooja-se* ***shiv-ki puranii*** *neha-ne* ***kitab*** *kharidi.* *

Pooja shiv old neha book bought.

1.1.1 Passive Voice in Hindi

In the same vein as the differences mentioned above, Hindi passives differ from English passives on a few accounts. Firstly, Hindi allows passivization of univalent, intransitive verbs (see sentences 3a and 3b). Magier (1987) defines valence as "the number of obligatory participant roles present in the cognitive organization of the scene conveyed by a particular verb". These verbs often become bivalent and transitive when used in a passive voice in Hindi as in 4a and 4b. Sentences 4a and 4b also include an implied agent who is omitted from the sentence. It is when such bivalent verbs are used that Hindi passives are mostly presented without expressed agents and form agentless passives.

3a) *anda pak gaya.*

egg cooked.

The egg cooked.

3b) *gilas gir gaya.*

glass dropped/fell down

The glass fell down.

4a) *anda pakaya gaya.*

egg cooked

The egg was cooked.

4b) *gilas giraya gaya.*

glass dropped/fell down.

The glass was dropped.

Secondly, and more importantly, the Hindi passive is not considered an exact alternative to the English passive especially with regard to the agent of the sentence. Hindi passives frequently allow the omission of agents with transitive verbs (Shapiro, 1989) (see examples 4a and 4b). In fact, passive sentences in Hindi were traditionally used without an expressed agent where the agent was often indefinite and generic and/or easily discernible from context (Davison, 1980). These is true for a lot of languages, including English and Italian.

Magier (1987) posits that transitive verbs vary in the degree to which they fulfil the transitivity prototype requirements[6]. For example, the verb 'kill' is more transitive in the sentence *John killed Bill'* than in the sentence *The lightning killed Bill*. This is because lightning is a less prototypical agent that has neither intention nor volition. Passive sentences demote the agent by shifting focus away from them; therefore, also making sentences with unspecified agents are less transitive than sentences with specified agents. This also results in Hindi passives with univalent verbs such as 3a and 3b being less transitive 4a and 4b. Examples 4a and 4b illustrate a bivalent scene, but the passivization of the sentences demote the agent out of the structure. In examples 3a and 3b on the other hand, the passivization focuses only on the change of state of the patient but does not demote the agent. Thus, while 4a and 4b maintain the 'role' of the cognitive agent despite being agentless passives (Pandharipande, 1981); sentences 3a and 3b do not allow what causes the action to be a part of the cognitive scene. In the Hindi experiment reported in Chapter 4, we focues only on passives with bivalent transitive verbs.

It can also be noted from the examples 3a-4b that the passives are marked with "*gaya*", a form of the auxiliary verb *-jaa* ('to go'). In the earlier registers of Hindi, passives used with *-jaa* were restricted and unable to have an expressed agent. However, the agent was always inferable from context or was indefinite and generic. They were also specifically used to

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[6] "a) The action is performed by a prototypical agent (i.e. a specific, definite actor, acting intentionally and of his own volition); b) The action is outward-directed; c) The action is performed upon a prototypical patient (i.e. a specific, highly salient patient); d) There is some specifiable outcome of the action, that can be stated in terms of some complete change of state of the patient; e) This outcome makes the patient the most salient participant in the scene." (Magier 1987).

express capability. However, over the last century and a half, it has become possible to use such passives to convey more neutral meaning and with expressed agents. This has been considered to be an influence of the English formal language (Davison, 1980; Kachru, 1970; Prasithrathsint, 1988). For example, in the sentence below, the usage of the agent (raam) is not obligatory.

e.g. *raam-se ravi-ko peeta nahin gaya.*

raam ravi beat not

Raam was unable to beat up Ravi.

However, while omitting the agent (raam) still leaves the sentence grammatical, it loses the meaning associated with the "internally determined capability" of the agent. Similar constructions are also found in Marathi, Nepali, Punjabi, Kashmiri (Pandharipande, 1979; 1981) and in Bengali and Malayalam (Mohanan, 1994). In Hindi, when an expressed agent is used in passive sentences, it is followed by a postposition *se,* (*ke) dwara* (the Sanskritized version) or (*ke) hathon* (Shapiro, 1989).

In general, passivization of a verb leads to four main changes in Hindi sentences: (i) the main verb of the active sentence appears in its perfective form in the passive sentences; (ii) the verb *jana* ('to go') is used as an auxiliary verb; (iii) the subject of the active sentence is followed by the postpositions *se*, *(ke) dwara* (by means of), *(ke) haathon* (by hands of; (iv) if the verb *hona* ('to be') is used in the active sentence, it follows the auxiliary verb *jana* ('to go') in the passive sentence (Prasithrathsint, 1988).

It is also worth noting that Hindi only allows passivization of verbs that represent volitional acts. For example, 5a is acceptable but 5b is not.

5a) *larki se andar aaya jata hai.*

girl inside come

The girl comes in.

5b) *hawa se andar aaya jata hai.* *

air inside come

Air comes in.

1.1.2 Ko usage

Ko is a marker often used in Hindi sentences. It can be an obligatory or optional marker. In its obligatory position in active sentences, it marks semantic case relations, i.e., it specifically marks the noun/nominal that it is attached to. When it is optional in active sentences, it is generally used as a 'dative/accusative marker'[7]. It is optional with direct objects in that it is reliant on the semantic property of the noun and is not tied to the syntactic slot. *Ko* always occurs with proper nouns or personal pronouns and is most frequently used with human common nouns. While the usage is not mandatory, its usage with other pronouns is relatively rare (Magier, 1987). In addition, cases where *ko* is optionally used with the direct object, principle of specificity or definiteness seems mandatory (see examples 6a – 6d) (Saksena 1980; Masica, 1982; Junghare, 1983).

E.g. 6a) *Darzi bulao.*

tailor call.

Call **a** tailor.

[7] The term dative is used to refer to the functions of the experiencer and the goal. The term accusative is used because the *ko* marker when the position of direct object is occupied by a nominal.

6b) *Darzi* ***ko*** *bulao*.

tailor call.

Call **<u>the</u>** tailor.

6c) *Ram ne kitab jalaai*.

ram book burned.

Ram burnt **<u>a</u>** book.

6d) *Ram ne us kitab* ***ko*** *jalaai*.

ram that book burned.

Ram burnt **<u>that</u>** book.

In other words, the salience of a direct object is determined by its animacy and specificity. Thus, in Hindi actives, *ko* is a marker of this salience. *Ko* also appears to reinforce the transitivity of the sentence because specificity and salience of the patient are key to the transitivity prototype (see footnote 1).

Ko is also used optionally or obligatorily in Hindi passives. However, in passive sentences, *ko* is used with the object (patient) of the active sentence. In this case however, the use of *ko* does not affect the specificity of the patient or its position on the animacy hierarchy. Instead, as in the examples below, the latter highlights an intentional action by the agent whereas the former does not (Magier, 1987). Sentence 7a implies that shanti's death could have been an accident, whereas 7b implies that she was intentionally killed.

7a) *shanti mari gayi*.

shanti killed

Shanti was killed.

7b) *shanti* ***ko*** *mara gaya*.

shanti killed

Shanti was killed (murdered).

1.1.3 Verb agreement in Hindi

The verb agreement between Hindi actives and passives is different in that in the actives, the verb agrees with the subject of the sentence (see 8a) and in the passive, it agrees with object of the passive sentence (see 8b). In particular, the verb agrees with the object of a passive sentence in number, gender, and tense only when it is not followed by a postposition. However, when the subject and object are followed by a postposition (*se* and *ko* in this instance) , the verb and the auxiliary do not agree with either the subject or the object. Instead, the masculine, singular form of the main verb and the auxiliary verb (8c) are used (Kachru, 1966).

8a) *aadmi*$_{\text{(M.SG-SBJ)}}$ *chitthiya*$_{\text{(F.PL-OBJ)}}$ *parthta*$_{\text{(M.SG-VB)}}$ *hai*. – Active

man letters reads ~

8b) *aadmi*$_{\text{(M.SG-SBJ)}}$ *se chitthiya*$_{\text{(F.PL-OBJ)}}$ *parhi*$_{\text{(F.PL-VB)}}$ *jati hai*. – Passive

man letters reads ~

8c) *aadmi*$_{\text{(M.SG-SBJ)}}$ *se chitthiyon*$_{\text{(F.PL-OBJ)}}$ *ko parha*$_{\text{(M.SG-VB)}}$ *gaya*. – Passive

man letters reads ~

~The man reads the letters.

1.1.4 Frequency of Passives in Hindi

Many studies offer anecdotal information regarding the use of Hindi passives in different contexts. However, there are a few systematic investigations on this issue are limited. A recent study by Bolgün & Mangla (2017) analysed 15 editorials in English from the New York Times and 15 editorials in Hindi from Navabharat. Editorials were used as they are thought to be a good reflection of cultural conventions and writing contexts (e.g. Tirkkonen-Condit & Lieflander-Koistinen,1989). The authors found that each of the 15 editorials of the New York Times had on average 3.4 passive constructions, with editorials having an average length of 540.2 words. The 15 Navbharat editorials on the other hand had an average of 6.9

passive constructions, with an average length of 385.4 words. If we assume each passive construction in the English editorials was 7 words long (e.g. the boy was chased by the girl), passive constructions would constitute approximately 5% of the constructions in the editorial. This is in keeping with Gil & Menn (2006). Similarly, in the case of Hindi, if one assumes that all passives are 4-word agentless sentences as is common in Hindi (e.g. *larki ko chidhaya gaya*, the girl was teased), passive constructions would amount to ~10% of the constructions in the editorial. While this is twice as frequent as English passives, it is considerably lower than the 28-35% used by SI users.

APPENDIX D
CHAPTER 3 – PILOT SUMMARY

The Hindi experiment used declarative active and passive sentences and pictures in a sentence-picture verification task. In the pilot, the pictures were tested with the active and passive sentences, both in the canonical SOV order; and passives in the non-canonical OSV word-order. Due to Hindi's relatively free-word-order nature, rich morphology and auxiliary system, we expected the actives and both types of passives to be comprehended with comparable ease. However, performance on the OSV passives was below chance level (~45%). Consequently, this structure was excluded from the main experiment. The main experiment used modified pictures (based on participant performance and feedback) along with the declarative actives and SOV passives. An example of the stimuli is given below. All stimuli are reported in Appendix D.

Active – दुल्हन सहेली को सजाती है।
d̪ʊlhan[SG.FEM] sahe:li:[SG.FEM] ko:[POST] sadʒa:t̪i:[3.SG.FEM.PRS] hɛ:
The bride readies (decorates) the friend.

Passive – सहेली द्वारा दुल्हन को सजाया जाता
sahe:li: [SG.FEM] dva:ra:[POST] d̪ʊlhan[SG.FEM] ko:[POST] sadʒa:ya:[3.SG.M.PFV] dʒa:t̪a:[AUX.HAB]
है।
hɛ:
The bride is readied (decorated) by the friend.

APPENDIX E

CHAPTER 3 – STIMULI

DA - गायिका लड़की को पकड़ती है।

The singer holds the girl.

DP - गायिका द्वारा लड़की को पकड़ा जाता है।

The singer is held by the girl.

DA - ड्राइवर लड़के को चिढ़ाता है।

The driver teases the boy.

DP - ड्राइवर द्वारा लड़के को चिढ़ाया जाता है।

The boy is teased by the driver.

DA - खिलाड़ी आदमी को पीटता है।

The player beats the man.

DP - खिलाड़ी द्वारा आदमी को पीटा जाता है।

The player is beaten up by the man.

DA - हवालदार ड्राइवर को टोकता है।

The constable stops the driver.

DP - हवालदार द्वारा ड्राइवर को टोका जाता है।

The driver is stopped by the constable.

DA - अध्यापक छात्र को डराता है।

The teacher scares the student.

DP - अध्यापक द्वारा छात्र को डराया जाता है।

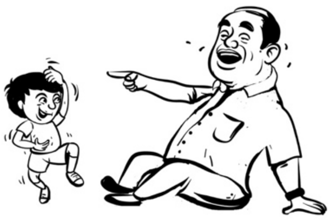
The student is scared by the teacher.

DA - वकील आदमी को हराता है।

The lawyer defeats the man.

DP - वकील द्वारा आदमी को हराया जाता है।

The man is defeated by the lawyer.



DA - बेटा पिता को हँसाता है।

The son makes the father laugh.

DP - बेटे द्वारा पिता को हँसाया जाता है।

The father is made to laugh by the son.

DA - बढ़ई इंजिनियर को डाँटता है।

The carpenter scolds the engineer.

DP - बढ़ई द्वारा इंजिनियर को डाँटा जाता है।

The engineer is scolded by the carpenter.

DA - किसान बावर्ची को बुलाता है।

The farmer calls the cook.

DP - किसान द्वारा बावर्ची को बुलाया जाता है।

The cook is called by the farmer.

DA - बेटी माँ को चूमती है।

The daughter kisses the mother.

DP - बेटी द्वारा माँ को चूमा जाता है।

The mother is kissed by the daughter.

DA - बच्ची औरत को रोकती है।

The child stops the woman.

DP - बच्ची द्वारा औरत को रोका जाता है।

The woman is stopped by the child.

DA - पिता शिशु को सुलाता है।

The father puts the baby to sleep.

DP - पिता द्वारा शिशु को सुलाया जाता है।

The baby is put to sleep by the father.

DA - फ़ौजी नेता को भूलता है।

The soldier forgets the politician.

DP - फ़ौजी द्वारा नेता को भुलाया जाता है।

The politican is forgotten by the soldier.

DA - औरत लड़की को खाना परोसती है।

The woman serves food to the girl.

DP - औरत द्वारा लड़की को खाना परोसा जाता है।

The girl is served food by the woman.

DA - लड़की पुलिसवाली को उठाती है।

The girl helps up the policewoman.

DP - लड़की द्वारा पुलिसवाली को उठाया जाता है।

The policewoman is helped up by the girl.

DA - नर्तकी अभिनेत्री को पढ़ाती है।

The dancer teaches the actress.

DP - अभिनेत्री द्वारा नर्तकी को पढ़ाया जाता है।

The dancer is taught by the actress.

DA - शिकारी कसाई को मारता है।

The hunter hits the butcher.

DP - कसाई द्वारा शिकारी को मारा जाता है।

The butcher is hit by the hunter.

DA - पुलिसवाला डाकू को धमकाता है।

The policeman threatens the dacoit.

DP - डाकू द्वारा पुलिसवाले को धमकाया जाता है।

The dacoit is threatened by the policeman.

DA - नर्स बच्ची को छूती है।

The nurse touches the child.

DP - बच्ची द्वारा नर्स को छुआ जाता है।

The child is touched by the nurse.

DA - बच्चा माली को छूता है।

The child touches the gardener.

DP - माली द्वारा बच्चे को छूआ जाता है।

The child is touched by the gardener.

DA - दुल्हन सहेली को सजाती है।

The bride readies (decorates) the friend.

DP - सहेली द्वारा दुल्हन को सजाया जाता है।

The bride is readied (decorated) by the friend.

DA - सहेली रानी को चौंकाती हैं।

The friend surprises the queen.

DP - रानी द्वारा सहेली को चौंकाया जाता है।

The friend is surprised by the queen.

DA - माली लड़के को भगाता है।

The gardener chases the boy away.

DP - लड़के द्वारा माली को भगाया जाता है।

The gardener is chased away by the boy.

DA - मुजरिम न्यायाधीश को देखती है।

The criminal looks at the judge.

DP - न्यायाधीश द्वारा मुजरिम को देखा जाता है।

The criminal is seen by the judge.

DA - पेंटर खिलाड़िन को बचाती है।

The painter saves the player.

DP - खिलाड़िन द्वारा पेंटर को बचाया जाता है।

The painter is saved by the player.

DA - माँ खिलाड़िन को गुदगुदाती है।

The mother tickles the player.

DP - खिलाड़िन द्वारा माँ को गुदगुदाया जाता है।

The mother is tickled by the player.

DA - चोर हवालदार को गिराता है।

The thief trips the constable.

DP - हवालदार द्वारा चोर को गिराया जाता है।

The thief is tipped by the constable.

DA - छात्रा अध्यापिका को घूरती है।

The student stares at the teacher.

DP - अध्यापिका द्वारा छात्रा को घूरा जाता है।

The student is stared at by the teacher.

DA - चोरनी पुलिसवाली को बाँधती है।

The thief ties up the policewoman.

DP - पुलिसवाली द्वारा चोरनी को बाँधा जाता है।

The thief is tied up by the policewoman.

FDA - नौकर राजा को छुपाता है।

The servant hides the king.

FDP - नौकर द्वारा राजा को छुपाया जाता है।

The king is hidden by the servant.

FDA - दादी पोती को चूमती है।

The grandmother kisses the granddaughter.

FDP - दादी द्वारा पोती को चूमा जाता है।

The granddaughter is kissed by the grandmother.

FDA - अभिनेत्री नेता को नज़रअंदाज़ करती है।

The actress ignores the politician.

FDP - अभिनेत्री द्वारा नेता को नज़रअंदाज़ किया जाता है।

The politician is ignored by the actress.

FDA - पत्रकार अभिनेता को ढूँढता है।

The journalist looks for the actor.

FDP - पत्रकार द्वारा अभिनेता को ढूँढा जाता है।

The actor is looked for by the journalist.

FDA - कर्मचारी मालिक को घूरता है।

The employee stares at the owner.

FDP - कर्मचारी द्वारा मालिक को घूरा जाता है।

The owner is stared at by the employee.

FDA - औरत लड़की को खाना परोसती है।

The woman serves food to the girl.

FDP - औरत द्वारा लड़की को खाना परोसा जाता है।

The girl is served food by the woman.

FDA - दर्ज़ी पुजारी को चौंकाता है।

The tailor surprises the priest.

FDP - पुजारी द्वारा दर्ज़ी को चौंकाया जाता है।

The priest is surprised by the tailor.

FDA - पोता दादाजी को पानी पिलाता है।

The grandson ‘feeds’ water to the grandfather.

FDP - दादाजी द्वारा पोते को पानी पिलाया जाता है।

The grandson is ‘fed’ water by the grandfather.

FDA - जासूस गायक को गिराता है।

The spy (makes the) singer fall.

FDP - गायक द्वारा जासूस को गिराया जाता है।

The spy is (made to) fall by the singer.

FDA - मरीज़ डॉक्टरनी को डांटती है।

The patient scolds the doctor.

FDP - डॉक्टरनी द्वारा मरीज़ को डांटा जाता है।

The patient is scolded by the doctor.

FDA - नौकरानी मालकिन को सुलाती है।

The maid puts the boss to sleep.

FDP - नौकरानी द्वारा मालकिन को सुलाया जाता है।

The boss is put to sleep by the maid.

FDA - छात्र वकील को रोकता है।

The child stops the lawyer.

FDP - वकील द्वारा छात्र को रोका जाता है।

The lawyer is stopped by the child.

APPENDIX F
CHAPTER 4 – PILOT SUMMARY

Three pilots were conducted before finalising the stimuli for the experiment. The aim of the first pilot was to check for the effectiveness of the pictures and the stimuli. Based on participant performance, and subjective feedback, changes were made to four pictures before running the second pilot. Participant performance and feedback reflected the effectiveness of the pictures, but also an issue with processing lengthy sentences within the given time frame. As a result, in the third pilot, grammatically legal, truncated versions of the sentences were used. The modified pictures and truncated sentences were finally used in the main experiment. The effectiveness of truncated sentences for a sentence-picture verification task was seen in Finocchiaro et al (2015). Examples of the truncated sentences used in the final version of the experiment are shown below. All the stimuli used in the experiment is reported in Appendix G.

Declarative Active (DA):
guida la chitarrista
'gwida$_{\text{[3.SG.PRS]}}$ la$_{\text{[ART.SG.FEM]}}$ kitar'rista$_{\text{[SG.FEM]}}$
The woman guides the guitarist

Declarative Passive (DP):
è guidata dalla donna
ɛ gwi'data$_{\text{[3.SG.PRS.PASS]}}$ 'dalla$_{\text{[PREP.SG.FEM]}}$ 'dɔnna$_{\text{[SG.FEM]}}$
The guitarist is guided by the woman

Comparative of Majority (MAC):
è più magra della chitarrista
ɛ$_{\text{[3.SG.PRS]}}$ 'pju$_{\text{[ADV.COMP]}}$ 'magra$_{\text{[ADJ.SG.FEM]}}$ 'della$_{\text{[PREP.SG.FEM]}}$ kitar'rista$_{\text{[SG.FEM]}}$
The woman is thinner than the guitarist
Comparative of Minority (MIC):
è meno magra della donna
ɛ$_{\text{[3.SG.PRS]}}$ 'meno$_{\text{[ADV.COMP]}}$ 'magra$_{\text{[ADJ.SG.FEM]}}$ 'della$_{\text{[PREP.SG.FEM]}}$ 'dɔnna$_{\text{[SG.FEM]}}$
The guitarist is less thin than the woman

Appendix G

Chapter 4 – STIMULI

Practice Items

DA - registra il professore

The student records the professor

DA - registra lo studente

The professor records the student

DP – è registrato dal studente

The professor is recorded by the student

DP – è registrato dal professore

The student is recorded by the professor.

MAC - è più pelato del professore

The student is more bald than the professor

MAC – è più pelato dellostudente

The professor is more bald than the student

MIC – è meno pelato del professore

The student is less bald than the professor

MIC - è meno pelato dello studente

The professor is less bald than the student

DA – salva l'attrice

The florist saves the actress

DA – salva la fioraia

The actress saves the florist

DP – è salvata dalla fioraia

The actress is saved by the florist

DP – è salvata dalla attrice

The florist is saved by the actress

MAC – è più raffinata dell'attrice

The florist is more refined than the actress

MAC – è più raffinate della fioraia

The actress is more refined than the florist

MIC – è meno raffinate dell'attrice

The florist is less refined than the actress

MIC - è meno raffinata della fioraia

The actress is less refined than the florist

DA – spaventa il calciatore

The firefighter scares the footballer

DA - spaventa il pompiere

The footballer scares the firefighter

DP – è spaventato dal pompiere

The footballer is scared by the firefighter

DP – è spaventato dal calciatore

The firefighter is scared by the footballer

MAC - è più forte del calciatore

The firefighter is stronger than the footballer

MAC – è più forte del pompiere

The footballer is stronger than the firefighter

MIC – è meno forte del calciatore

The firefighter is less strong than the footballer

MIC – è meno forte del pompiere

The footballer is less strong than the firefighter

DA - spruzza il ragazzo

The plumber sprays the boy

DA - spruzza l'idraulico

The boy sprays the plumber

DP – è spruzzato dall'idraulico

The boy is sprayed by the plumber

DP – è spruzzato dal ragazzo

The plumber is sprayed by the boy

MAC - è più curvo del ragazzo

The plumber is more curved than the boy

MAC - è più curvo dell'idraulico

The boy is more curved than the plumber

MIC - è meno curvo del ragazzo

The plumber is less curved than the boy

MIC - è meno curvo dell'idraulico

The boy is less curved than the plumber

Main Experimental Items

DA – abbraccia il nipote

The grandfather hugs the grandson

DP – è abbracciato dal nonno

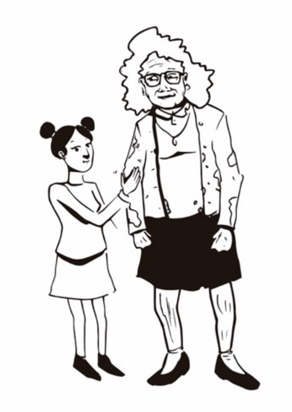
The grandson is hugged by the grandfather

MAC – è più peloso del nonno

the grandson is hairier than the grandfather

MIC – è meno peloso del nipote

the grandfather is less hairy than the grandson



DA - accarezza la nipotina

the grandmother caresses the granddaughter

DP – è accarezzata dalla nonna

the granddaughter is caressed by the grandmother

MAC – è più disordinata della nonna

theh granddaughter is messier than the grandmother

MIC – è meno disordinata della nipotina

The gradmother is less messy than the granddaughter

DA - accusa la cameriera

The cook accuses the waitress

DP – è accusata dalla cuoca

The waitress is accused by the cook

MAC – è più stanca della cameriera

The cook is more tired than the waitress

MIC – è meno stanca della cuoca

The waitress is less tired than the cook

DA – aiuta la ciclista

the teacher helps the cyclist

DP – è aiutata dalla maestra

The cyclist is helped by the teacher

MAC – è più vecchia della maestra

the cycist is older than the teacher

MIC – è meno vecchia della ciclista

The teacher is less old than the cyclist

DA – applaude la batterista

the singer Applauds the drummer

DP – è applaudita dalla cantante

the drummer is applauded by the singer

MAC – è più grassa della cantante

The drummer is fatter than the singer

MIC – è meno grassa della batterista

the singer is less fat than the drummer

DA – aspetta l'avvocato

the guitarist waits for the lawyer

DP – è atteso dal chitarrista

the lawyer is waited for by the guitarist

MAC – è più ansioso del chitarrista

The lawyer is more anxious than the guitarist

MIC – è meno ansioso dell'avvocato

The guitarist is less anxious than the lawyer

7.DA – assale il ladro

The firefighter Attacks the thief

DP – è assalito dal pompiere

The thief Is attacked by the firefighter

MAC – è più barbuto del pompiere

The thief is more bearded than the firefighter

MIC – è meno barbuto del ladro

The firefighter is less bearded than the thief

DA – bacia la cuoca

the drummer Kisses the cook

DP – è baciata dalla batterista

The cook is kissed by the drummer

MAC – è più giovane della cuoca

the drummer is younger than the cook

MIC – è meno giovane della batterista

is less young than the drummer

The cook is less young than the drummer

DA – chiama la poliziotta

the driver Calls the policewoman

DP – è chiamata dall'autista

the policewoman is called by the driver

MAC – è più dritta della autista

the policewoman is straighter than the driver

MIC – è meno dritta della poliziotta

the driver is less straight than the policewoman

DA – colpisce il contadino

the hunter hits the farmer

DP – è colpito dal cacciatore

the farmer is hit by the hunter

MAC – è più bagnato del contadino

The hunter is more wet than the farmer

MIC – è meno bagnato del cacciatore

The farmer is less wet than the hunter

DA – dipinge il padre

The son paints the father

DP – è dipinto dal figlio

The father is painted by the son

MAC – è più elegante del figlio

The father is more elegant than the son

MIC – è meno elegante del padre

The son is less elegant than the father

DA – consola il violinista

the doctor Consoles the violinist

DP – è consolato dal medico

The violinist is consoled by the doctor

MAC – è più calmo del medico

is more calm than the doctor

the violinist is calmer than the doctor

MIC – è meno calmo del violinista

The doctor is less calm than the violinist

DA – disegna il ragazzo

The teacher draws the boy

DP – è disegnato dal maestro

The boy is drawn by the teacher

MAC – è più debole del ragazzo

The teacher is weaker than the boy

MIC – è meno debole del maestro

The boy is less weak than the teacher

DA – fotografa la bambina

the nurse Photographs the child

DP – è fotografata dall'infermiera

the child is photographer by the nurse

MAC – è più sporca dell'infermiera

the child is dirtier than the nurse

MIC – è meno sporca della bambina

the nurse is less dirty than the child

DA – guida la chitarrista

The woman Guides the guitarist

DP – è guidata dalla donna

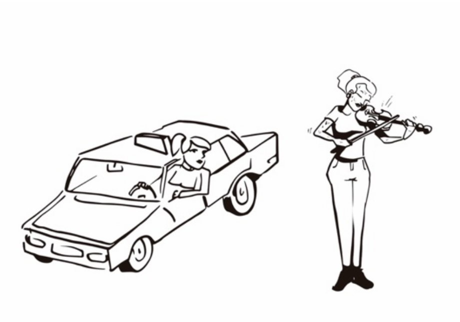
The guitarist is guided by the woman

MAC – è più magra della chitarrista

The woman is thinner than the guitarist

MIC – è meno magra della donna

the guitarist is less thin than the woman



DA – guarda l'autista

the violinist sees the driver

DP – è guardata dalla violinista

the driver is seen by the violinist

MAC – è più concentrata della violinista

The driver Is more focused than the violinist

MIC – è meno concentrata dell'autista

the violinist is less focused than the driver

DA – indica il contadino

The lawyer indicates/points at the farmer

DP – è indicato dall' avvocato

The farmer is indicated/pointed at by the lawyer

MAC – è più allegro dell'avvocato

The farmer is happier than the lawyer

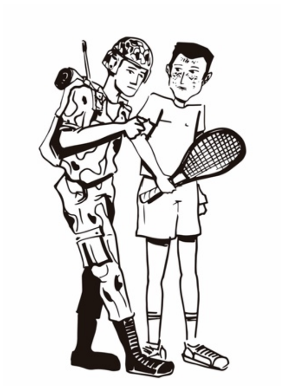
MIC – è meno allegro del contadino

The lawyer is less happy than the farmer

DA – lega l'idraulico
The cop ties up the plumber
DP – è legato dal vigile
The plumber is tied up by the cop
MAC – è più alto dell' idraulico
The cop is taller than the plumber
MIC – è meno alto del vigile
The plumber is less tall than the cop

DA – paga il macellaio
the hunter pays the butcher
DP – è pagato dal cacciatore
The butcher is paid by the hunter
MAC – è più povero del cacciatore
The butcher is poorer than the hunter
MIC – è meno povero del macellaio
The hunter is less poor than the butcher

DA – pettina la madre
the daughter combs the mother's hair
DP – è pettinata dalla figlia
the mother's hair is combed by the daughter
MAC – è più riccia della madre
the daughter's hair is curlier than the mother's
MIC – è meno riccia della figlia
the mother's hair is less curly than the daughter's



DA – pizzica il soldato
The tennis player pinches the soldier
DP – è pizzicato dal tennista
The soldier is pinched by the tennis player
MAC – è più lentigginoso del tennista
The soldier is more freckled than the tennis player

MIC – è meno lentigginoso del soldato

the tennis player is less freckled than the soldier

DA – saluta il cameriere

The soldier Salutes the waiter

DP – è salutato dal soldato

the soldier is saluted by the waiter

MAC – è più basso del soldato

The waiter is shorter than the soldier

MIC – è meno basso del cameriere

The soldier is less short than the waiter

DA – schiaffeggia l'attore

the man slaps the actor

DP – è schiaffeggiato dall'uomo

the actor is slapped by the man

MAC – è più paffuto dell'uomo

The actor is chubbier than the man

MIC – è meno paffuto dell'attore

The man is less chubby than the actor

DA – sgrida il calciatore

The cyclist Scolds the footballer

DP – è sgridato dal ciclista

The footballer is scolded by the cyclist

MAC – è più muscoloso del ciclista

The footballer Is more muscular than the cyclist

MIC – è meno muscoloso del calciatore

The cyclist is less muscular than the footballer

DA – sorregge la ragazza

the policewoman supports the girl

DP – è sorretta dalla vigilessa

the girl is supported by the policewoman

MAC – è più pulita della vigilessa

The girl is cleaner than the policewoman

MIC – è meno pulita della ragazza

The policewoman is less clean than the girl

DA – spinge la ballerina

the nurse pushes the dancer

DP – è spinto dall'infermiera

the dancer is pushed by the nurse

MAC – è più rugosa dell'infermiera

The dancer is more wrinkled than the nurse

MIC – è meno rugosa della ballerina

The nurse is less wrinkled than the dancer

DA – tira il pilota

The dancer Pulls the pilot

DP – è tirato dal ballerino

the pilot is pulled by the dancer

MAC – è più smilzo del ballerino

The pilot is slimmer than the dancer

MIC – è meno smilzo del pilota

The dancer is less slim than the pilot

DA – tocca la bambina

The grandmother Touches the child

DP – è toccata dalla nonna

the child is touched by the grandmother

MAC – è più spossata della bambina

the grandmother is more exhausted/worn-out than the child

MIC – è meno spossata della nonna

The child is less exhausted/worn-out than the grandmother

DA – trattiene la fioraia

The woman Holds the florist

DP – è trattenuta dalla donna

The florist is held by the woman

MAC – è più sudata della fioraia

The woman Is more wet than the florist

MIC – è meno sudata della donna

The florist is less wet than the woman