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The Syntax-Space Effect

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ABSTRACT

Previous research has linked the concept of number and other ordinal series to space via a spatially-oriented number line. Other researchers have shown that language as well may have an underlying spatial representation, though this seems to be tied to visual scene recognition and production and is potentially an idiosyncratic effect of a limited set of concrete verbs. In this dissertation, employing a novel method that measures the underlying spatial biases of actors in transitive sentences, I show that findings from previous studies showing a relationship between transitivity and space reflect an interaction between word order in the sentence, order in the causative structure, and space (specifically, lateral space). This syntax-space effect is based in manual action, when stimuli occur within hand-space, and is most strongly observed when responses are made with the left hand. These latter observations indicate roles of both hemispheric processing and manual biases in the mental representations of objects appearing in space, perhaps serving as a function of their potential for action. Thus, syntax appears to be at least partially grounded in both action and space.

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List of Abbreviations

ACE.. Active-sentence compatibility effect

ASL.. American Sign Language

BA.. Brodmann's area

BOLD.. Blood-oxygen-level dependent

E1, E2, etc. .... Experiment 1, 2, etc.

fMRI.. Functional magnetic resonance imaging

IPL.. Inferior parietal lobe

LEar.. Left ear

LHand .... Left hand

LH .... Left hemisphere

MARC.. Linguistic markedness association of response codes

MEPs.. Motor evoked potentials

MNS.. Mirror neuron system

NP .... Noun phrase

S1, S2, etc. .... Sentence 1, 2, etc.

SNARC .... Spatial-numerical association of response codes

STEARC .... Spatial-temporal association of response codes

SR.. Stimulus-response

RT .... Response time

REar .... Right ear

RHand .... Right hand

RH .... Right hemisphere

SMG .... Supramarginal gyrus

SVO, SOV, etc. .... Subject-verb-object, subject-object-verb, etc.

USC IRB .... University of South Carolina Institutional Review Board

VP .... Verb phrase

CHAPTER 1

INTRODUCTION

Section 1.1 – Overview

The purpose of this dissertation is to explore the relationships between the syntactic concept of transitivity, spatial cognition (focusing on *lateral*, or left-right, space), and manual-motor processes. In this introduction I will discuss a number of different areas of research in psychology, linguistics, and neuroscience pertinent to these three concepts, attempting to show how they may be related. The sections will cover: language and space, mirror neurons and embodied cognition, motor resonance and spatial cognition in language processing, cross-linguistic word order, orthographic direction, verb directional biases, the relations between hand and space, and finally the relations between language and hand. The purpose of covering this material is to provide the necessary background to understand the motivations behind the experiments that follow. The basic theses are: transitivity is embodied in manuospatial processes; the relationship between transitivity, space and hand is not due solely to epiphenomenal influences of writing direction and word order (though these are important factors in their own right); and the relations between these concepts have cascading effects on development at both an individual and cultural level.

Section 1.2 – Language and space

Language is not spatial in nature. It is an abstraction of the reality it describes. This quality is partly what makes language such a powerful tool, resulting in endless ways to communicate ideas. Classic language areas (i.e. Broca's and Wenicke's areas) are dissociated from regions of the brain that have been implicated in spatial processing (i.e. the superior parietal lobes, the right temporal lobe, etc.; Karnath, Ferber, & Himmelbach, 2001; Vallar, 2007). This would seem to be a necessary feature of language. After all, if language were subsumed by regions that are responsible for spatial cognition, one would expect to find frequent co-occurrence of spatial and linguistic disorders, but as these are rare (Suchan & Karnath, 2011) it seems clear that language and space are largely modular systems. However, despite the non-spatial nature of language, the language system necessarily interacts with spatial cognition. This must be true, as we can quite easily describe the arrangement of objects in a scene; when asked to do so we can give someone directions to the bank; or we can visualize the play-by-play of a baseball game broadcast over the radio. All of these linguistic tasks involve spatial processing to some degree, and yet if we analyze the individual components of these spatial utterances, we will find that the relation between the language and the space they describe is largely imprecise. Nevertheless, we can easily understand the utterances and verify their relation to the world. Let us take as an example the description of an arrangement of objects: “On my desk there is an apple. To the left of the apple is a mouse. Beneath the mouse is a mouse pad.” On the surface this seems to be a reasonable description, but if you consider the imprecision of the spatial terms *on, to the left of, beneath* there is much that is lacking. The reason for this lack of precision is that the utility of language is in its ability to generalize and abstract physical reality into concepts. Just as tokens of animals or colors can be referred to by type, resulting in some loss of variation and specificity, our tools for describing spatial relations are schematic in nature. *To the left of* applies equally well to an object three inches to the left as it does to an object three miles to the left. Given the infinite possible variations in spatial positioning, it seems highly unlikely (not to mention it would be highly unproductive) for a language to specify exact coordinate positioning (Kosslyn, 1994; Laeng, 1994; Levinson, 1996). Thus, language in the face of a world of analogical variation is categorical either as a result of or perhaps in order to enhance our mental efficiency (Klippel & Montello, 2007). In discussing the relationship between language and space, an obvious starting point is to identify the areas where the two indisputably overlap, these being spatial frames of reference, locative prepositions, sign languages, and tracking spatial relations in the mental model.

Spatial frames of reference

The location of an object is typically expressed via the use of figure (the object that is to be located), ground (a reference object), and some locative element describing the spatial relation between the two (Kemmerer & Tranel, 2000). The locative element in English, of course, is the preposition. While most languages of the world have tens of thousands of words used to denote different objects (i.e., the potential figures and grounds), they have only around one hundred prepositions (Landau & Jackendoff, 1993). As those authors note, languages contain so few prepositions that they are considered to be a closed-class part of speech. In describing spatial relations, the speaker has several options regarding the frame of reference they choose to adapt. Linguists have identified three such frames of reference: egocentric, allocentric, and geocentric (Landau, Dessalegn, & Goldberg, 2010). Consider, for example, Figure 1.1 below:

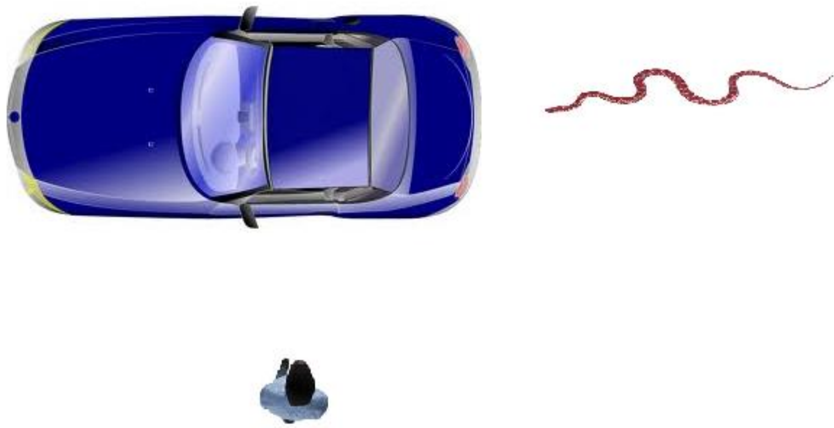


Figure 1.1. Multiple spatial reference frames. A situation in which the man has several possibilities for describing the location of the snake in relation to the car, and where the frame of reference he uses could result in some ambiguity.

If the man were to adopt an egocentric reference system, he would describe the snake as being to the right of the car (i.e., *his* right). Using an allocentric reference system centered on the car, he would likely say "the snake is behind the car." Finally, using a geocentric reference system, the man could say "the snake is east of the car."

Languages vary in both the manner in which space is partitioned and the types of reference frames used. For example, Levinson (1996, 1999) and Pederson et al. (1998) have shown how the Tzeltal, a tribe in South America, exclusively use a geocentric system that follows the contours of their territory. This involves the use of terms such as *uphill* and *downhill*. Other tribes, such as the Arandic or the Arrente, use only a geocentric frame of reference to describe space, with four canonical directions corresponding to *north, south, east,* and *west* (Pederson et al., 1998). An African language, Hausa, describes the front of objects lacking an intrinsic spatial frame (e.g., a tree) as the side facing away from the observer, indicating that speakers translate their frame of reference onto such objects, as opposed to in English where the frame of reference would be projected and then rotated 180° (Hill, 1982; Tranel & Kemmerer, 2004). Additionally, Hausa children learning English are shown to switch their spatial strategies when speaking in English, but to revert back to translational spatial reference frames when speaking in Hausa (Hill, 1982; Levinson, 1996). The fact that we can use so many different systems to describe space does seem to suggest that language may influence our spatial cognition to some degree, but also that thinking and talking about space is extremely flexible.

Locative prepositions

A number of studies have examined the neural underpinnings of preposition usage (e.g., Kemmerer & Tranel, 2000; 2003; Noordzij et al., 2008; Tranel & Kemmerer, 2004). Kemmerer and Tranel (2000) reported two patients showing a double dissociation between visuospatial processing and locative preposition usage. Specifically, patient 1978JB was afflicted with a left hemisphere (LH) lesion including the inferior and middle temporal gyri, the inferior pre- and post-central gyri, the anterior supramarginal gyrus (SMG), and insula, whereas patient 1688PG was afflicted with a right hemisphere (RH) lesion including the inferior and middle frontal gyri, the inferior and middle temporal gyri, the pre- and post-central gyri, the inferior parietal lobule (IPL), the temporal pole, and insula. These two patients performed a battery of tests examining their visuospatial performance and ability to comprehend locative prepositions. 1978JB (LH-damaged) displayed impairment on all of the locative preposition tests but performed within the normal range on the visuospatial battery. 1688PG (RH-damaged), on the other hand, performed normally on each of the preposition tests but was impaired on the visuospatial tests.

Kemmerer (2005) subsequently showed that the spatial and temporal meanings of prepositions are also neuroanatomically distinct and thus can be independently impaired. Kemmerer posits that the left SMG is a crucial structure for spatial preposition comprehension, while the left persiylvian area appears necessary for the processing of their temporal analogues. These two studies build upon a large body of literature which suggests crucial differences between the human parietal cortices (e.g., De Renzi, 1982; Goldberg, 1989; Hannay, Varney, & Benton, 1976; Kinsbourne & Warrington, 1962; Kosslyn, 1994; Kosslyn et al., 1989; Laeng, 1994; Mayer et al., 1999; Mehta & Newcombe, 1991; Taylor & Warrington, 1973; Warrington & Rabin, 1970). The right parietal lobe appears to specialize in precise coordinate spatial representations, whereas the left is more specialized in categorical spatial representations (Castelli, Glaser, & Butterworth, 2006; Kemmerer & Tranel, 2000; Kosslyn et al., 1989).

Thus, it seems that a lot of the imprecision in spatial language is a result of differences between how the left and right parietal lobes handle information. We would thus expect that if there were cases of language groups with rich spatial linguistic expressions used in a noncategorical manner, these expressions would be handled by the right parietal lobes and not the left. Indeed, this is precisely the situation with users of sign language.

Sign languages

Signed languages differ from spoken languages in several ways important to our discussion of language and space. Liddell (1995; 2003) argues that there are three distinct types of space that signers make use of when communicating: Real Space, Surrogate Space, and Token Space. Real Space is the mental representation of the physical reality surrounding the signer, a conceptualization shared by users of both signed and spoken languages. Signers can make use of Real Space by referring to referents around them through deictic pointing (much as speakers would via co-speech gesture). Surrogate Space is used to describe things or people not physically present. The signer can invoke a mental space consisting of full-sized, invisible surrogates that can then be referred to via pointing. These surrogates can take on first-, second-, or third-person roles in the discourse. Finally, Token Space involves a smaller mental space that is limited in size by the extent of the signer's signing space (i.e., the space surrounding the signer in which signs are produced). Tokens are three-dimensional entities that are limited to a third-person role in the discourse. This then is the first distinction between signers and speakers: signers have a much more complex organization of space, involving (at least) three levels of spatial representation superimposed upon one another[1]. A second important distinction is that spoken languages are almost[2] completely linear due to the physical constraints of speech and listening, whereas signers can convey multiple points of information simultaneously (Emmorey, 1999). For example, an object can be represented by a certain kind of hand shape called a classifier. At the same time the signer can place this sign at some coordinate within signing space, perhaps a location distant from the signer's other hand, indicating either metaphorical or actual distance

[1] Of course, due to the nature of human cognition and language, these multiple spaces would naturally allow spatial recursion in complex discourse scenarios, adding further sophistication to the signer's conception of space.

[2] I must qualify spoken language as "almost" linear as prosodic cues clearly enable the transfer of at least a second layer of information on top of basic phonological cues. Nevertheless, the constrained dimensionality of the spoken speech stream is reduced in comparison with that of the signed stream.

between the two objects. The result is multiple propositions being produced simultaneously. Related to the previous point, the third main difference between signed and spoken languages is that the primary method of conveying spatial relations in signed languages is not through the use of a closed class set of words such as prepositions. Rather, signers make direct use of space, resulting in much more precise spatial descriptions than is feasible in spoken languages (Emmorey et al., 2005). Fourth, entities within a discourse can be referenced by placing a referent in some part of the sign space and then subsequently referring to that entity via pointing to that part of the sign space (Almor et al., 2007; Liddell, 2003), be it through the use of Surrogate or Token Space. And finally, signed languages contain "agreeing verbs", transitive verbs which connect two locations in sign space corresponding to the subject and object of a sentence (Emmorey, 1999; see Figure 1.2; see also Liddell, 2003 for an alternative view on verb agreement in signed languages).

Although sign languages make such rich use of space in communication, signed languages and spoken languages are nearly indistinguishable at a neuroanatomical level. For example, signing aphasia results from LH damage, just as in spoken languages. Evidence from neuroimaging studies supports this finding, showing that lexical activation in both signers and hearers occur in largely overlapping neural structures (e.g., Emmorey et al., 2003). Where the two types of languages differ, however, is in their use of spatial expressions. In right-handed signers, right hemisphere damage results in disordered use of spatial relations (Emmorey, 1999), and neuroimaging studies show that spatial language (i.e., the use of prepositions and the signing equivalent of prepositions) involves the IPL bilaterally in signers and only the left IPL in speakers (Emmorey et al., 2005;

Noordzij et al., 2008). This latter finding harkens back to our discussion of the differences between the two IPLs and specifically Kosslyn's (1987; Kosslyn et al., 1989; Kosslyn et al., 1995) argument that the left parietal cortex is more involved in categorical spatial relations while the right is better suited for precise, coordinate spatial processing.

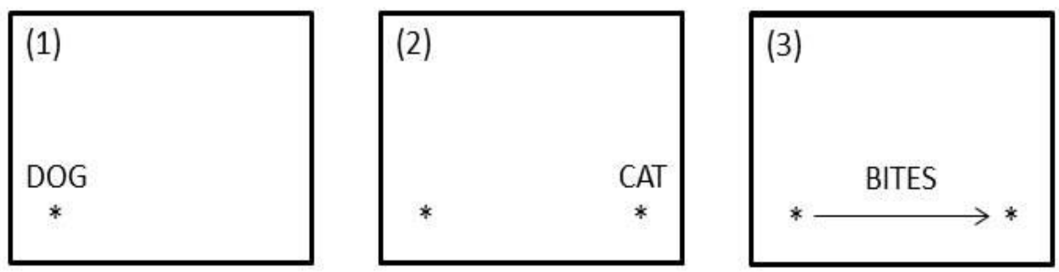


Figure 1.2. Signing verb agreement. In the first panel, DOG is signed to the left side. In the second panel, CAT is signed to the right side, while the left asterisk marks the memory trace of DOG. In the third panel, the sign for BITES is made in a motion that connects the trace of DOG to the trace of CAT, meaning "the dog bites the cat" (example from Emmorey, 1999).

Tracking space in the mental model

The use of locative prepositions in a narrative urges readers to construct detailed spatial representations of the text. The text itself has been likened to a set of instructions on how to build these representations (Zwaan, Langston, & Graesser, 1995). The mental worlds readers create (named *situation models* by van Dijk & Kintsch, 1983, or *mental models* by Johnson-Laird, 1983) are molded from a certain perspective (e.g., the protagonist's or the narrator's) with certain parts of the narrative foregrounded or in focus. This perspective is associated with a deictic center (Morrow, 2001; Duchan, Bruder, &

Hewitt, 1995), which is constantly in flux with new events occurring and information being updated. It has been argued that the situation model can be updated along five different dimensions: time, space, causation, intentionality, and protagonist (Zwaan, 1999; Zwaan & Radvansky, 1998). The index of space (the focus in this section) has received much attention by researchers (e.g., Glenberg, Meyer, & Lindem, 1987; O'Brien & Albrecht, 1992; Rapp & Taylor, 2004; Rapp, Klug, & Taylor; 2006; Rinck & Bower, 1995, 2000; Tversky, 1992; de Vega, 1995). The goal of much of this research is to uncover the depth to which readers naturally construct spatial models while reading discourse.

One of the first studies to address the issue of spatial (and protoganositic) representations in the discourse model was Glenberg, Meyer, & Lindem (1987). These authors examined the effect of the distance between the protagonists and other objects, using two main conditions: association (in which the reference object is attached to the protagonist) and dissociation (in which the reference object is detached from the protagonist). They found that anaphors that referred back to the dissociated object antecedent were processed slower than anaphors referring back to the associated object antecedent, which may reflect implicit foregrounding of objects in the proximity of the deictic center of the discourse.

This issue of spatial proximity was further investigated in a number of studies in which participants memorized maps (and object locations in the rooms of the maps) and then read stories describing a protagonist moving through that map in order to accomplish tasks in different rooms (e.g. Horton & Rapp, 2003; Morrow, Greenspan, & Bower, 1989; Rapp, Klug, & Taylor, 2006). When participants were probed about the current location of the protagonist (i.e., judging whether the protagonist was located in the same room as a target object), they responded faster to objects that were positioned near the protagonist, indicating that they had constructed a spatially rich situation model of the narrative. Horton and Rapp (2003) showed that what is perceptually available to the protagonist is also more available in the reader's memory in a study that did not involve map memorization, but rather just reading stories and answering comprehension questions. However, other researchers have provided evidence that readers (when not instructed to do so) do not develop such rich spatial representations, but rather that the types of tasks readers engage in affect the degree to which the element of space is explicated in these mental models (O'Brien & Albrecht, 1992). In other words, if prompted to do so, readers are able to construct very rich spatial models, but when left to their own devices, readers tend to only do this to a limited extent.

To conclude the main points of this section, the language of space for speakers is somewhat impoverished. Clearly, thinking and talking about space is flexible, but it seems to be rare that speakers or comprehenders delve into intentionally iterated spatial representations or precise object localization. However, this is mainly the case for spatial language. As I will attempt to show, beyond this focus on spatial semantics and sign language, there may be a deeper relationship between language and space.

Section 1.3 – Mirror neurons and embodied cognition

I will now take a slight digression into motor-linguistic relations before turning once again to space. Traditional accounts of the nature of meaning have posited that it is established via an amodal symbol system (e.g., Fodor, 1975; Kintsch, 1998), i.e., that meaning is abstracted and independent from input modality. This amodal symbol system has been likened to a memory archive of extraordinary flexibility. In contrast with this view, other theorists have proposed that meaning is coded as part of a perceptual symbol system (Barsalou, 1999). Crucially, this system predicts there to be an analogical relationship between the actual referent and the related mental representation. This perceptual symbol system has also gone under the moniker of "grounded cognition" and "embodied cognition".

According to Barsalou (2008) the concept of grounded cognition dates back to Ancient Greek philosophy, and its revival in the 20th century stems mainly from research in speech perception. Liberman et al. (1967) and Liberman and Mattingly (1985) proposed that the objects of speech perception are actually the motor codes used to produce those objects. In other words, perception is silent (or perhaps inhibited) rehearsal, and thus our ability to perceive speech is intricately tied to linguistic motor production. Indeed, imaging studies have shown that listening to speech does lead to the activation of frontal motor regions involved in producing speech (Wilson, Saygin, Sereno, & Iacoboni, 2004; Wilson & Iacoboni, 2006). While this motor theory of speech perception has received much criticism (e.g., Galantucci, Fowler, & Turvey, 2006), the basic idea of a shared mechanism between perception and motor response codes has also found support in other realms of psychology, most notably via the discovery of *mirror neurons.*

Di Pellegrino et al. (1992) found in a series of studies that neurons in the premotor cortex of the macaque monkey respond to both the performance and perception of reaching and grasping motions. These mirror neurons do not reflect the mere shared circuitry of perception and action. Rather, they seem to respond to *action understanding*.

For example, these neurons fire only when the macaque observes a reaching motion toward an object, not if the same reaching motion is performed towards empty space. They even respond if the reaching motion is directed towards an object the monkey knows is present, though occluded from its field of view (Umiltà et al., 2001). Similarly, these neurons respond to both auditory and visual input associated with the action, e.g., watching and listening to the mastication of a nut (Kohler et al., 2002). Fogassi et al. (2005) showed that this effect also goes beyond interpreting actions, suggesting an understanding of intentions, as mirror neurons selectively responded to picking up apples when the subsequent action would be eating as opposed to placing the apple in a container located on the monkey's shoulder. Thus, the literature on mirror neurons in nonhuman primates indicates a motor-basis of cognition. What about in humans?

A number of techniques have been used to investigate the proposed existence of a mirror neuron system (MNS) in humans (see Rizzolatti & Craighero, 2004, for a review). In addition to the previously mentioned motor basis of speech perception, other forms of action have also been shown to evoke activation of these mirror neurons. For example, Fadiga et al. (1995) showed that observation of both transitive and intransitive arm movements produced nonspecific transcranial magnetic stimulation-induced motor-evoked potentials (MEPs) in the right hand and arm. These findings contrast somewhat with those discussed above in nonhuman primates in that they involve responses to motor activity and observed transitive and intransitive activity, whereas mirror neurons in nonhuman primates dissociate between transitive and intransitive actions. However, given the difference in techniques (i.e., single-cell recordings vs. MEPs), this difference may not be that meaningful. Nevertheless, a subsequent MEP study (Maeda, Kleiner-

Fisman, & Pascual-Leone, 2002) showed that, indeed, mirror neurons in humans tend to respond more generally, probably allowing for the greater ability of humans than nonhuman primates to imitate actions, especially when the purpose of those actions may not be fully understood (Rizzolatti & Craighero, 2004).

A number of neuroimaging studies have also provided evidence for an MNS in humans. An example of such a study comes from Buccino et al. (2001) who used fMRI to measure activation associated with viewing video clips of actors performing both transitive and intransitive actions that involved either the mouth, arm, or leg. Action observation produced somatotopically organized activation in premotor cortex, similar to regions activated during motor performance. Part of this activation involved BA 44, a region included in Broca's area (Amunts & Zilles, 2006; Broca, 1861), often associated with syntactic processing (Bookheimer, 2002) but also a host of other processes such as visual search and attention (Fink et al., 2006), phonological processing (Zatorre et al., 1996), grasping (Decety et al., 1994), and musical perception and production (Meyer & Jäncke, 2006). Activation was also observed in the IPL, but only for transitive actions. These parietal foci were organized somatotopically just as they were in frontal areas. Another study (Buccino et al., 2004) demonstrated that this activation is not restricted to the observation of conspecifics, but that observation of a heterospecific (e.g., humans observing nonhuman primates) can also produce activation of the MNS if the action observed is part of the human motor repertoire.

Part of the MNS in nonhuman primates is located in the homologue of Broca's region (Rizzolatti & Craighero, 2004). This shared neuroanatomy between the mirror neuron and linguistic systems led Rizzolatti and Arbib (1998) to propose that language developed out of a more primitive MNS. They describe the type of communication that may occur through two parties involved in an action: motor prefixes (subtle cues passing back and forth between observer and actor) broadcast action intention, facilitate action recognition, and then subsequently through imitative responding reciprocate signals of understanding from the observer. Despite the speculative nature of Rizzolatti and Arbib's proposal, later on we will see that indeed mirror neurons do seem to be inextricably linked to language comprehension and production. Indeed, the principles behind these motor prefixes share common assumptions with the Interactive Alignment Theory in language processing (Pickering & Garrod, 2004), in which, as humans communicate with one another, they begin to adapt similar mental linguistic representations (from phonology and syntax up to higher levels such as semantics and discourse models).

Section 1.4 – Sensorimotor resonance in language processing

Turning back to language, let us look at how specifically the MNS may relate to language processing and also how language may be grounded in visuospatial processing. The cases of abstract language and number will also be considered

Motor resonance

Connections between language processing and the MNS are at the heart of theories of grounded cognition (Fischer & Zwaan, 2008). One of the seminal research studies in this vein, which ties in neatly with the work on mirror neurons, is Glenberg and Kaschak's (2002). In their study, participants read sentences which described actions with implied directional motion. For example, *open the drawer* implies motion away from the speaker and *close the drawer* implies motion towards the speaker. Participants made plausibility judgments of these types of sentences by moving their hand to press a button located either away from or towards their bodies. The authors found that response time (RT) was facilitated when the implied action direction of the previously read sentence matched that of the response direction (termed the Action-Sentence Compatibility Effect; ACE). They conceive of meaning as being created by environmental affordances influencing how one can act or respond in a situation. The sentences used in Glenberg and Kaschak's experiments are highly conducive to creating mental simulations, being written in the second-person perspective. Thus, the comprehension of these sentences involves the activation of motor programs that would be necessary to act in the described situations (Kaschack & Glenberg, 2000). In a subsequent study, Glenberg, Sato, and Cattaneo (2008) showed that motor processing can interfere with subsequent linguistic processing. In their study participants moved several hundred beans from one jar (distant from the body) to another (close to the body). Afterwards, they judged the plausibility of sentences with implied directional transfer and were slower to respond to sentences with implied motion toward the body, indicating that the motor effectors which were overworked from the bean transfer portion of the experiment were interfering with semantic processing.

In addition to these behavioral studies, a number of neuroimaging studies have examined motor resonance in language. One such study, Hauk, Johnsrude, and Pulvermuller (2004), compared the BOLD activation associated with action verbs relating to the face, leg, and arm to actual movements of these body parts. They found that activation associated with action verbs was arranged in a somatotopic manner, in structures either overlapping or adjacent to the same structures involved in performing those actions, a finding reminiscent of the studies examining the MNS in humans.

Another study showed that damage to motor areas can result in linguistic processing difficulties associated with body parts represented by the damaged areas (Neininger & Pulvermuller, 2001). Taken together, these studies relate the MNS found in humans and nonhuman primates to language comprehension.

Visuospatial resonance

Now let's return to visuospatial processes and language, a research thread that stems from work on situation models described in detail earlier. This area of investigation complements the work on motor resonance in language processing, showing a similar effect for grounding in visuospatial processes. Stanfield and Zwaan (2001) asked whether the implied orientation of objects mentioned in a sentence influenced participants' subsequent judgments of images depicting those items. Participants read sentences and after each sentence decided whether an image of an object had been in the previous sentence. Interestingly, the implied orientation of the objects in the sentence primed faster RTs on pictures that matched the implied orientation. For example, after reading the sentence "Bob hammered the nail into the floor" participants would more quickly identify a vertically-oriented nail than a horizontally-oriented one, and crucially they would be faster to identify a horizontally-oriented nail following "Bob hammered the nail into the wall" than a vertically-oriented one.

In a follow up study, Zwaan, Stanfield, and Yaxley (2002) extended those findings beyond object orientation to the shape of objects. Participants read sentences such as "The ranger saw the eagle flying in the sky" and again judged whether a subsequent image was present in the previous sentence. Participants were faster to judge the image if it matched the implied state of the object mentioned in the sentence. For example, in the case of the eagle flying, participants would judge the eagle faster if it had outstretched wings than if it were perched in a nest. This does suggest that language comprehension involves some degree of perceptual simulation. The authors note that given the limitations of attention and working memory, the simulation is likely of a schematic nature and not a fully realized, detailed image.

Zwaan and Yaxley (2003), in a study looking at the grounding of semantics in visuospatial representations, had participants make semantic relatedness judgments to word pairs that were either related or not and which (among related pairs) were presented in either canonical or non-canonical vertical positions relative to one another. For example, one item (*coffee* and *foam*) presented *coffee* either below or above *foam* in canonical or non-canonical conditions respectively. When word pairs were presented to the left visual field (and hence the RH), there was an effect of position, but when presentation was to the right visual field (LH), position had no effect. For my purposes here, this study provides two important points: first, underlying spatial representations may be sensitive to hemispheric processing differences; and second, an experiment exploring the effects of spatial representations need not rely on images to accomplish its goals, in contrast to the picture recognition/verification designs (e.g., Stanfield and Zwaan, 2001; Zwaan, Stanfield, and Yaxley, 2002).

Abstract language

Another important issue to consider is the notion of abstract concepts and metaphor, which may seem to pose a challenge to an embodied view of cognition. Indeed, researchers have found conflicting evidence for the embodiment of abstract concepts. Even before the resurgence in the interest in embodied cognition, Lakoff

(Lakoff & Johnson, 1980; Lakoff, 1987; Lakoff, 1992) proposed that abstract concepts are typically conveyed via metaphorical phrases. Additionally, all forms of abstract thought can *only* be understood via these conceptual relations, which are grounded in the body, experience, and the physical world. Lakoff supplies us with an abundance of examples, the ones listed below being the metaphor of achieving purpose as mechanical object acquisition:

> They just handed him the job.
>
> It's within my grasp.
>
> It slipped through my hands.
>
> He is pursuing a goal.
>
> Reach for /grab all the gusto you can get.
>
> Latch onto a good job.
>
> Seize the opportunity. (Lakoff, 1992, p. 24)

Lakoff and Johnson's proposition in many ways echoes the concept of Talmy's (2000) force dynamics, which conceives of all interactions as being processed in a manner similar to how we conceive of physical forces acting on one another. In any sentence there are (either explicitly or implicitly) an agonist and an antagonist, which may take the roles of agents, patients, subjects, objects, actors, experiencers, themes, etc. Verbs express motion, be it actual, metaphorical, or unrealized, and this motion is a result of the struggle to action between the antagonist and agonist, whose strengths will naturally vary. As Glenberg (1997) points out, "these basic entities and relations can be based on bodily experiences such as pushing and being pushed, moving objects, and so forth" (p. 15), and they can apply to any abstract concept, such as the verb *want*, which, according to Talmy's analysis, implies psychological pressure or force toward some goal.

Building on these traditions begun by Lakoff and Johnson and Talmy, a number of imperical studies have shown that abstract concepts may have sensorimotor representations. For example, Glenberg et al. (2008) showed that abstract verbs of transfer produce an ACE similar to the one found for concrete transfer verbs. Barsalou and Wiemer-Hastings (2005) also showed that participants associate abstract concepts with sensorimotor properties in a manner similar to concrete concepts. Richardson et al. (2003) found that abstract concepts (e.g., *argue* or *increase*) produce a Perky effect[3] on the implied axis of the concept (e.g., *increase* leads to interference on the vertical axis). However, other studies have failed to produce these effects. For example, Bergen et al. (2007) showed that metaphors do not lead to a Perky effect along the implied spatial axis. Also, Rüschemeyer, Brass, and Friederici (2007), measuring the BOLD response to metaphorical uses of words like *grasp* (i.e., abstract metaphorical use of action verbs), found no activation in motor cortex, while Desai, Binder, Conant, Mano, and Seidenberg (2011) found that the involvement of sensorimotor regions in sentence processing decreases as abstraction increases.

Time, space, and number

One such abstract concept that we make use of on a regular basis is time. As there is no sensory modality that can specifically measure time, we rely on metaphorical

[3] Perky (1910) found an interaction between mental imagery and perception. When participants imagined an object, they were more impaired in their ability to detect that object when it flickered on a screen. This was the case even when the presentation duration was about that of the threshold of conscious perception.

comparison in order to grasp the concept. Languages across the world consistently use spatial terms for this purpose. For example, English phrases such as *a week from today* or *next week* imply linear movement through time. Indeed, the word for *time* stems from the Latin *tempus*, meaning "space marked off" in reference to the practice of partitioning the sky to measure the time of day (Cassanto, Fotakopoulou, & Boroditsky, 2010). What's more, different languages will conceive of movement through time differently, which is reflected in the language. Compare Chinese "scrolling" time (*xia ge xingqi*, gloss: *down one week*, translation: *next week*), in which time flows from top to bottom scroll-like, to English (and other Western cultures) with its linear movement (*the week before, after*; Radden, 2006). Of course, these examples are somewhat exaggerated, as both English and Chinese can and frequently do adopt other timeline orientations. For example, *qiantian* means the day before yesterday and can be glossed as *front day*, adopting a horizontal perspective of temporal motion. In English, the terms *ascendant* and *descendant* use vertical timelines in order to describe the flow of generations, while the terms *above* and *below* are frequently used in writing to refer to preceding and subsequent textual information respectively. These exceptions aside, Boroditsky (2001) showed that spatial orientation can prime the processing of temporal expressions, and that these orientations match the preferred timeline axes of English and Chinese speakers. However, exposure to a language with a different metaphorical conception of time weakens the spatial priming of the mother tongue, much as we saw above in the shift of spatial frames in Hausa children learning English.

Number, another abstract concept, also appears to be rooted in spatial processing. Dehaene, Bossini, & Giraux, (1993) demonstrated that the numbers 1 through 4 prime responses towards the left side of space and the numbers 6 through 9 prime responses toward the right side of space, which they termed the Spatial-Numerical Association of Response Codes (SNARC) effect. Calabria and Rossetti (2005) further showed that numbers irrelevant to the task have a similar spatial-biasing effect. For example, bisecting a line composed of the number 9 will cause pointing to deviate to the right, while lines composed of the number 2 cause leftward deviations. Imaging studies suggest this number-space interface involves the left intraparietal sulcus (Walsh, 2003), an area also associated with saccade generation (Corbetta, 1998; Devinsky, 1992), mapping salience on visuospatial displays (Kusunoki, Gottlieb, & Goldberg, 2000), and the coordination and planning of reaching, pointing, and tool manipulation (Kolb & Whishaw, 2009; Laeng, 2006; Maher & Rothi, 2001; Vallar, 2007). This SNARC effect is quite flexible and appears to be related to how the concept of number is acquired. For example, orthographic direction affects which numbers prime which side of space (Dehaene, Bossini, & Giraux, 1993). Further explorations into the nature of the effect (e.g., via a crossed hands design) have shown the importance of the hand in magnitude processing (Wood, Nuerck, & Willmes, 2006).

Aside from time and number, magnitudes in general seem to share response codes (Bueti & Walsh, 2009). Letters of the alphabet and months of the year show similar left-to-right priming effects (Gevers, Reynvoet, and Fias, 2003). This effect can also be observed in the spatial bias of temporal judgments (though here it is termed the STEARC effect; Ishihara et al., 2008), where judgments of shorter stimulus onsets are made faster to the left than to the right, and vice versa for longer stimulus onset judgments. Additionally, Xuan et al. (2007) also observed that for stimuli presented for the same amount of time, *more* of something (e.g., 7 dots vs. 3 dots; bright lights vs. dim lights; big squares vs. small squares) is judged to last longer than *less* of something. These findings may have important implications for studies of linguistic-spatial relationships. For example, the SNARC literature (if indeed it can be connected with the language-space literature) would predict that any word appearing at the start of a sentence would show a left-side bias and any word at the end would show a right-side bias. Related to this concern is the linguistic markedness association of response codes (MARC effect; Nuerk, Iverson & Willmes, 2004), in which responses are facilitated when the stimulus and response share congruent linguistic markedness. When, for example, left and right hand responses are assigned to odd and even parity judgments respectively in a typical SNARC paradigm, RTs will be faster, as there is correspondence between the markedness of left and odd and right and even. With the reverse assignment, interference results.

I have presented evidence so far that semantic processing involves accessing sensorimotor representations: understanding is grounded in experience. Below, I will argue that this concept of embodiment may be applied to other apparently unrelated linguistic concepts. One such realm where this may be seen is in the word order of languages. Word order is especially relevant to this discussion when considering language as conveyed via the visuospatial medium of writing, where word order is reflected by relatively stereotypical distribution across space, but given the importance of word order in the temporal sequencing of linguistic elements in both speech *and* writing compounded with the theoretical connection between space and time, word order becomes even more of a crucial connection between language and space.

Section 1.5 – Word order

A transitive sentence involves three main components: the agent (subject), the action (verb), and the patient or goal (object). This is not merely a quality of language, but rather it is an observation of events in the world. Even intransitive events may possess some notion of transitivity, as many intransitive verbs involve implicit goals (e.g., *to walk to the store*, *to think about an old friend*). When ordering the three main components of the transitive action, there are six possible outcomes: subject-verb-object (SVO), SOV, OSV, OVS, VSO, or VOS. All of these word order can be found among the languages of the world; however, they are not equally distributed (see Table 1.1).

Table 1.1 Word orders from a sample of 1188 languages

Basic order	Number	Percentage	Example
SOV	565	48	Japanese
SVO	488	41	English
VSO	95	8	Irish
VOS	25	2	Nias
OVS	11	1	Hixkaryana
OSV	4	0.5	Nadëb

Note: Adapted from Dryer (2005).

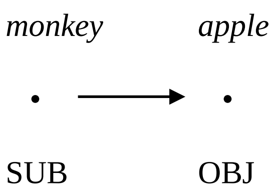
Thus, languages across the world largely have a preference for SVO or SOV word orders. Also, pidgins and International Sign (a pidgin developed by signers from different backgrounds) tend to use an SVO ordering (though this is more variable; Supalla & Webb, 1995). Kemmerer (2012, reporting from Dryer, 2007) notes that many of the languages included in this sample have flexible word orders but that what has been counted as a basic word order is a sequence that is: 1) most frequently used in that particular language, 2) the least linguistically marked, and 3) pragmatically neutral.

There are two main trends apparent from these data: for one thing, languages tend to put the subject before the object, a characteristic which is known as *subject salience*; secondly, the verb and object tend to be adjacent to one another, which is termed *verb-object contiguity* (Greenberg, 1963, Kemmerer, 2012, Tomlin, 1986). Why is it the case that languages tend to gravitate towards these structures?

Subject saliency

First, let us look at subject saliency. Take the scenario: *The monkey grabbed the apple.* This sentence describes an agentive subject *the monkey*, a patient/object *the apple*, and a transitive verb describing the relationship between the two entities: *grabbed.* This sentence describes an ordered series of events: 1) there is first no action; 2) the monkey initiates a movement executed towards the apple; 3) the movement is finished with the monkey's hand enclosing the apple. What is interesting about this analysis of the motion event is that the method that the majority of the world's languages use to describe this event uses a temporal ordering mirroring the causal order of the actual event (Kemmerer, 2012). Croft (1991) refers to this as the *causal order hypothesis*: "The grammatical relations hierarchy . . . corresponds to the order of participation in the causal chain" (p. 186). The hierarchy goes as follows: subject < object < oblique.[4] Thus, underlying the surface structure of the sentence *The monkey grabbed the apple* is a temporal sequence of the events which can be conveyed as follows:

[4] Oblique refers to a subsequent role, such as a benefactive, recipient, or result (Croft, 1991). Croft also considers some obliques as antecedent roles, in which case they typically precede objects in the causal chain. As I am only concerned with subjects and objects (or agents and patients) in this chapter, I will not be further considering obliques.



In addition, the exact same underlying pattern holds if the sentence is in passive voice: *The apple was grabbed by the monkey.* Langacker (2001) proposed that word order, and thus the conceptual evolution of a linguistic utterance over time, is a central component in that utterance's meaning. There are a number of crucial factors to consider when thinking about word order: how something is expressed (the surface structure used), the conceptual order, and the real-world ordering of events. Thus, there is a sequence of events, which tends to be represented iconically in this same sequence when real-world entities are assigned to linguistic objects. Furthermore, the misalignment of the three factors Langacker mentions results in increased processing time (e.g., the longer processing time required for passives over actives; Ferreira, 2003). This framework thus predicts that the notion of time is an important aspect in linguistic meaning and is tied into the very grammatical structure of a sentence. This furthermore provides a coupling between language and the magnitude-space effects mentioned above.

Thus, it seems that word order is not just an arbitrary convention of language, but rather it may be in some sense an iconic representation of the sequencing of events in the world. However, it is important to curb this argument slightly, because a large number of languages do not use this iconic temporal sequence. Nevertheless, Dryer (2006) notes that many of the recordings of variable word orderings may be suspect, and thus the exact count may not be entirely accurate. Also, a number of linguists have argued that the concept of subjecthood may not apply to all languages of the world (Croft, 1991). Finally, an important point is that language is generally not considered to be iconic. Certain aspects of language are indeed iconic (e.g., certain types of co-speech gestures), but the sound of a word bears little relation to its meaning. Apparent exceptions to this rule are the Bouba/kiki effect and onomatopoeia (Ramachandran & Hubbard, 2001). However, the former of these exceptions may be due to implicit associations between the order of acquisition of phonology (e.g., *b* before *k*) and the types of objects infants and children are exposed to and allowed to explore (e.g., balls before knives), while the latter exception (onomotapoeia) varies grossly across languages (e.g., American horses *neigh*; Chinese horses *si*). While the iconicity of language may not seem to be entirely applicable when discussing the temporal mapping between real-world events and the temporal sequencing of words, I believe it is a highly relevant issue and is the explanation behind the propensity of subject-first word orders among the world's languages.

A clue as to how this connection could be made comes from sign language. The signs used in sign languages are not typically iconic, but there are some interesting similarities across different sign languages, indicating that they may have evolved into (i.e., over time been reduced to) non-iconic gestures. For example, across American, Danish, and Chinese sign languages, the sign for *tree* appears to retain an iconic vertical component (Corballis, 2002). In addition to the iconicity of certain signs, the form of signed transitive verbs (as mentioned previously) also retains the causal ordering of events. What is important to take into consideration is that, while modern languages may be somewhat arbitrary in the forms they use to describe the world, they may have evolved out of more iconic systems, for example ones in which the matching of the temporal ordering of linguistic events to real-world events was crucial to interpreting their meaning (see for example, Corballis, 2002; Rizzolatti & Arbib, 1998). Thus, the main point about subject salience is that subjects, who are typically the initiators of the action, are placed towards the beginning of the temporal sequence in order to iconically represent the causal structure. Of course, it is possible to have a subject who is a patient, but the passive voice is less preferred than the active voice across all languages of the world (Keenan & Dryer, 2007), and moreover passives are not as easily comprehended as actives (e.g., Caramazza & Zurif, 1976; Ferreira, 2003).

Verb-object contiguity

The second major trend of word order preferences in the world's languages is that the object and the verb tend to be adjacent to one another. This also may have at its root an iconic relation to the real-world event described in the sentence, which is namely that the state of the object is dependent on the verb (i.e., the verb affects the object). When an apple is grabbed, the apple is being affected, not the grabber. If we find a person holding a gun, we cannot presume that this person has shot someone; however, if we find someone with a bullet hole in his chest, we can safely say that he has been shot. In other words, the actor is only affecting the object through indirect means, via the action itself, which is what is responsible for the object's change in state. This may be why passivization allows the agent to be omitted. Indeed, the by-phrase of the passive does not even exist in some language (e.g., Arabic; Ryding, 2005), while in others (Chinese, for example) the agent phrases would typically be deleted before the patient phrase. This suggests an importance and perhaps even a necessity of retaining the patient information in the passive structure. Indeed, the entire purpose of passive sentences is to highlight the identity or state of the patient. Similarly, a transitive sentence in active form typically must retain all elements of its thematic structure. For an English example, take the place verb *put*. Note the possibilities for omission in English:

-I put the apple on the counter.

-Put the apple on the counter.

-*I put the apple.

-*Put the apple.

-*I put on the counter.

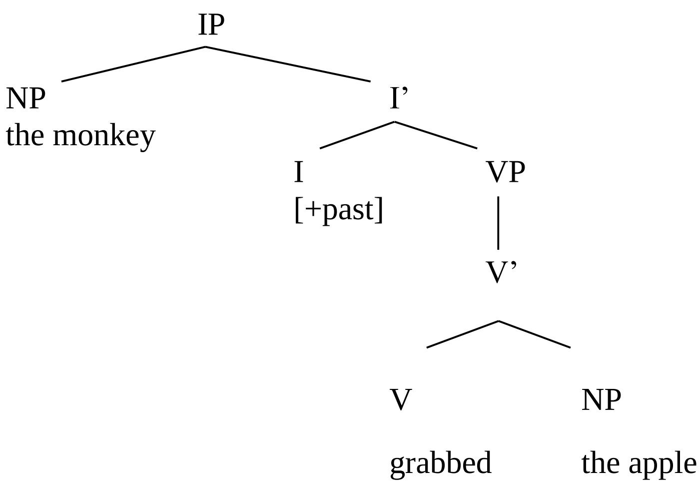
-*Put on the counter.

-*I put.

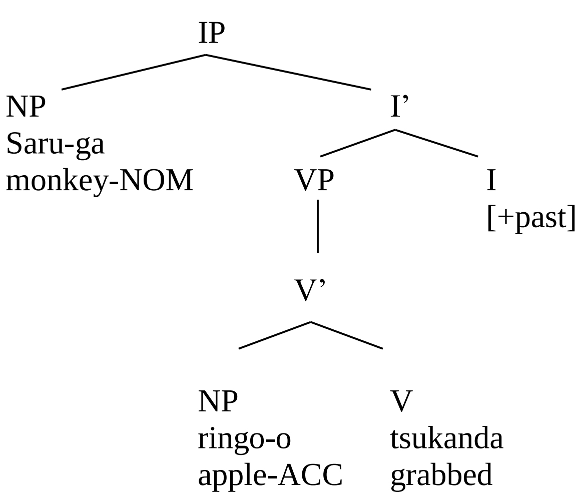
-*Put.

Any omission of object and place results in ungrammaticality, while subject omission indicates a command. However, if a thematic element can be omitted from a sentence, it is typically the subject and not the object (e.g., Gelormini-Lezama & Almor, 2011; Goldin-Meadow, 2005; Yang, Gordon, Henderick, & Wu, 1999).

In addition to this, generative grammarians have stressed the tight link between verb and object through analysis of the deep structure of transitive sentences. Although syntactic theory is constantly in flux, the principle that the direct object noun phrase (NP) is the daughter of the verb phrase (VP) with a transitive verb as its head (Carnie, 2007) is a constant feature. For example, let’s return to our original example: *The monkey grabbed the apple.* The deep structure of this sentence would be diagrammed as follows:



If we look at the structure of this sentence in a language other than English (Japanese, an SOV, for example), we find something very similar (S. Shoji, personal communication, August 20, 2013):



Hierarchically, these tree structures are exactly the same, differing only in branching directions in a few locations. This would suggest that in addition to tending towards certain preferred word orders, languages also possess similar underlying representations of action scenarios and that this is not just a quality of SVO languages. There is, then, a crucial link between the verb and the object of the sentence both in reality and proposed syntactic structure.

It is worth noting that transitive sentences can convey a wide range of scenarios, some of which describe agentive action and others that do not: for example, *This line parallels that line* (Kemmerer, 2012). Recall the previous discussion about abstract and metaphorical language comprehension (Lakoff, 1987; Lakoff, 1992; Lakoff & Johnson, 1980; Talmy, 2000) where it was suggested that human understanding is grounded in sensorimotor experience. Syntax (and here, transitive constructions specifically) may provide a mechanism, grounded in typical concrete action scenarios, for assisting our interpretation of abstract concepts via metaphorical extension.

To conclude, there are several striking things to note about the lack of diversity between how the languages of the world are structured. First, the majority of languages prefer either SOV or SVO word orders. Second, these orders are characterized by the tendency to produce the subject at the beginning of a sentence and also to group together the verb and the object. Third, these preferences seem to be the result of an attempt to capture the causal order of events in the world in the temporal relations of the string of words comprising a sentence. If we take a step back, this phenomenon may not seem as startling as it does at first glance. All humans are faced with the same laws of physics, and if, as Talmy (2000) proposed, cognitive grammar can be reduced to these basic properties of reality, there are only so many solutions a language can provide in order to describe that reality. Perhaps what is more surprising is that we encounter languages such as Modern Irish (a VSO) that defy the tendencies other languages lean towards. Of course, generative grammarians have shown that languages such as Modern Irish employ verb movement, where the verb moves out of a position near the object and lands at the front of the sentence (Carnie, 2007). Thus, it has been argued that even languages that do not follow the typical orders, have an underlying deep structure that seems to have more in common with SVO or SOV.

Finally, MacDonald (2013) has argued that there are three universal principles that constrain language production and that these may impact word order in everyday language. The first principle consists of producing the easiest element first, the second is plan reuse, and the third reduce interference. As a thought experiment, imagine two speakers from different linguistic backgrounds with no shared code for communication. One is a salt merchant, and the other a chicken vendor. Each wants what the other is selling. There are several salient elements that might arise in this exchange: the desire and goods of the salt merchant, and the desire and goods of the chicken merchant. The goods are not shared elements, while the desire for the other's goods are shared and thus perhaps more salient. In attempting to accomplish an exchange the salt merchant might point to himself and then the desired object. This initial construction, according to the MacDonald's second principle would propagate a series of similarly ordered sequences moving back and forth between the two merchants. Along similar lines, the third principle, especially in the construction of discourses would demand discourse entities sharing common features to be spaced apart. For example, of the four entities involved, salt merchant and chicken merchant have more in common with each other than with their goods, and at the same time chicken and salt have more in common as goods. Given the potential for semantically similar entities to interfere in short term memory, sentences produced using these four elements would naturally tend towards interleaving elements sharing semantic features: e.g. *I want chicken, you want salt?* These three principles may thus conspire to create stereotypical cross-linguistic patterns in syntactic element ordering.

This leaves us with the question of why language needs to maintain this causal order. Given the findings that passives are more difficult to comprehend than actives, it may also be the case that they are more difficult to produce. We will see next that embodiment might again be at the bottom of the word order phenomenon. To preview the discussion, verbs access action trajectories describing these causal sequences. Thematic roles need to be inserted into this sequence. If these actions verbs are grounded (Barsalou, 1999), then the role of agent, as the initiator of the causal sequence, will be more salient than the patient. At the same time, more cognitive resources would be required to fill the less salient patient role, and thus a delay (i.e., production later on in the stream of speech) would facilitate successful, disfluency-free production. This would also lead to the prediction that languages with flexible word orders should nevertheless favor SVO or SOV production, as speakers should be able to produce these structures faster than any of the other possible sequences (MacDonald, 2013).

Section 1.6 – Orthographic direction

Before considering verb directionality and its potential effects on language, an important and related issue to discuss is that of orthographic direction. To begin with, we may wonder why different languages (just as with word order), when solving the problem of mapping a temporal sequence (the speech stream) onto a spatial array (the written word), ended up using different orthographic directions. It seems that different languages could and would conceivably exhaust all possible different directions: for example, left-to-right, right-to-left, alternating direction by line, top-to-bottom, bottom-to-top, diagonally, etc. Again as with word order, we may initially expect that all of these possibilities are present among the languages of the world, and that they exist with relatively equal distribution. However, again this is a partially incorrect assumption. For one thing, nearly every possible (and logical) writing direction has been found among scripts both ancient and modern, but again, as was the case with word order, different writing directions are not evenly distributed across languages. The majority of the world's written languages are written from left to right horizontally (see Table 1.2).

Table 1.2. Directions of the world's known writing systems

Writing Direction	Percentage	Example Systems
Bostrouphedonic (bidirectional)	.024	Hungarian Runes
Left to Right Horizontal	.659	Cherokee, Latin, Tibetan
Left to Right Vertical Bottom to Top	.018	Batak
Left to Right Vertical Top to Bottom	.047	Mongolian
Right to Left Horizontal	.2	Arabic, Hebrew
Right to Left Vertical Bottom to Top	.006	Ancient Berber
Right to Left Vertical Top to Bottom	.047	Chinese

Note: Adapted from Ager (2013)

The second most common direction is right to left horizontally, but again nearly every possible direction is used by at least one writing system or another (though many of these are obsolete). Note that these statistics indicate *writing systems* and not languages (i.e., different languages may use the same writing system). If the orthographic direction of modern languages were to be considered, the story would become much more complicated, as many languages use multiple scripts and even multiple directions (e.g., Chinese, which can be written left to right horizontally, top to bottom from the right to left, and right to left horizontally on signs typically to evoke nostalgia; Ager, 2013). Nevertheless, a cursory look shows that left-to-right scripts now dominate.

Calvin (1983) offers an intriguing (though "just so") solution as to how this development might have taken place. The answer could lie in handedness. Before the invention of the moveable type or the computer which transformed writing into a bi-manual task with each hand contributing an equal share of labor, accountants pressed tokens into wet clay in order to keep track of debts (Schmandt-Besserat, 1981). Eventually, the chisel and hammer made these tokens superfluous. Then came ink and papyrus, and eventually the pen. Consider the physical differences between chiseling and writing with a pen. Right-handers tend to hold the chisel in the left hand and the hammer in the right. Now imagine you have the task of etching a story into a stone tablet. In order to increase the efficiency of the task you will probably want to position your hands in a way that you can still see what you are doing and what you have already done (perhaps to make sure the work in progress is aligned with the completed work). As the left hand is less obtrusive towards the sides of the gripping fingers, it would make more sense to move the chisel towards the left as writing (or chiseling) progresses, likely resulting in an orthography moving from the right to the left. As for writing with a pen (or quill), this involves inserting the tip of the writing device into the aperture created by the thumb, index, and middle fingers, effectively making the point of contact with the paper away from the hand. For right-handers, this makes the point face towards the left, while for left-handers the point faces towards the right. In order not to smudge the ink, it makes more sense to write in the direction away from the midline of the body, thus resulting in a left-to-right movement. Calvin's speculation is that right-to-left orthographies are a holdover from a time when languages were etched, while left-to-right orthographies developed as a result of avoiding ink smudges. Partial support for this argument may be found in the fact that Latin scripts were at earlier times in history etched in the right-to-left direction (Knight, 1996).

Thus, the apparent dominance of the left-to-right orthography is likely a result of an interaction between handedness and technological influence. In addition, during the Renaissance and subsequent colonial periods of the European powers, this technology (and perhaps ideology) was aggressively spread throughout the rest of the world. It is probable that during these periods, many cultures without writing systems developed ones reflecting the left-to-right patterns of the European Romance languages. Indeed, some Asian languages (e.g., the Hmong language and Vietnamese) abandoned traditional top-to-bottom logographic orthographies for the left-to-right Latin alphabet, mainly due to the influence of Christian missionaries throughout various periods in history (Jacques, 2002; Smalley, Vang, & Yang, 1990). Similarly, (mainland) Chinese writing was once written from top-to-bottom starting at the rightmost column and moving leftward, but this was largely abandoned for the left-to-right, top-to-bottom style currently in practice in mainland China.

In summary, the evolution of writing directions seems to have nothing to do with factors such as word order and (as I will discuss in the next section) verb directionality. Rather, it seems that the biggest influence on the development of writing direction was a combination of handedness and available technologies during the historical periods that were characterized by colonization. But in spite of this somewhat mundane explanation for a widespread phenomenon, the directionality of a writing system may have important consequences on how we process language, and it has proved to influence the result of a number of studies which I will discuss below.

Empirical evidence for this effect can be found in a study looking at the effects of writing direction on the conception of time. Bergen and Lau (2012) used participants from America, Mainland China, and Taiwan, to test how they mapped space onto time. American participants spoke English only. Mainland Chinese participants spoke Mandarin (and a few bilingual English speakers), which predominantly uses a left-to-right orthography. Taiwanese participants spoke Mandarin as well, but in Taiwan the writing system appears more evenly distributed across the three directional variants mentioned above. On each trial, participants were given stacks of cards, each card having a picture representing some stage of a process (e.g., growth of a tree, chicken, or person). Participants were instructed to order the pictures into the proper sequence of events. The authors found that English speakers only ordered the pictures in a left-to-right sequence. Mainland Chinese participants ordered the pictures left-to-right on most trials, but on a few they used a top-to-bottom order. Taiwanese participants were much more variable in their responses with a third of the responses using a left-to-right ordering, another third using a top-to-bottom ordering, and the last third divided between right-to-left, bottom-to-top, and circular. Thus, the results do seem to suggest that writing direction has an impact on how speakers of a language map space onto time. Of course, as the Boroditsky (2001) experiments showed, temporal semantics also come into play (e.g., temporal verticality), but these vertical terms were in use during the time when Chinese was written exclusively from the top-to-bottom and right-to-left. Thus, whether semantics influenced writing direction or vice versa will have to remain a chicken and egg question.

Section 1.7 – Verb directionality

So far I have discussed spatial semantics in language, embodiment, and the contributions of word order and orthography in (potentially) iconically representing sequences of events. There are, however, other realms in which space and language may interact. In this section I will address lateral biases in representing verbs.

One of the first studies to show that there may be an empirically observable relation between syntax and space came from Chatterjee et al. (1995). These authors describe the case of a left-handed patient (WH) who suffered from a right hemisphere stroke that left him agrammatic. Specifically, WH was unable to map between the subjects and objects of transitive sentences and the thematic roles (agent and patient). In one of the experiments from that study WH listened to transitive sentences in active or passive voice and selected between two pictures that either matched or mismatched the action. Crucially, all of the stimuli described circle and square cartoon characters, which effectively eliminated animacy plausibility cues. WH performed at chance for both active and passive sentences in this experiment, a somewhat surprising finding given that the underlying grammatical complexity of the passives led the researchers to predict that he would do better with actives than passives. Interestingly, if the direction of the action was controlled for, it was found he performed at ceiling. Specifically, he performed accurately on active sentences when they described left-to-right action, and best on passive sentences when they described right-to-left action. Thus, WH was using a spatiotemporal strategy to map syntax onto thematic structure. He heard a sequence of words and, lacking any ability to structure them syntactically, may have relied on salience in working memory, which would have been influenced by the order in the temporal sequence.

Several other studies have tested whether a similar effect to that observed in WH can be found in normal healthy participants. Chatterjee, Southwood, and Basilico (1999) showed that when drawing images, participants tended to place the agent of the action on the left side of the picture. In addition, they were faster in matching sentences to images, when the image depicted the agent of a transitive action on the left and the patient on the right. Maas and Russo (2003) tested whether the effects Chatterjee and colleagues had reported so far were due to the orthographic direction of the language spoken by participants (i.e., the left-to-right direction of English). They compare the performance of Italian and Arabic speakers on a similar sentence-picture matching task used in Chatterjee's experiments and found that Italian speakers showed shorter RTs to images with the agent on the left, and Arabic speakers to images depicting agents on the right, suggesting that indeed orthographic direction drives this effect. However, in addition to this, both language groups showed faster responses to images flowing in a left-to-right direction, which may suggest that in addition to orthography, language laterality is also contributing to the effect. Specifically, Chatterjee (2001) proposed that left-lateralized language individuals may process/envision transitive actions via a region in the left temporo-parieto-occipital junction, which is involved in left-to-right motion tracking. Additionally, left hemispheric regions are involved in launching contraversive saccades (Herter & Guitton, 2004), in which case left-to-right scene scanning may facilitate faster linguistic processing.

These studies together make a convincing story for a relationship between transitive actions and space. However, Altmann et al. (2006), using a larger *n* (18) of verbs than Maas and Russo (*n* = 4: *give, take, push,* and *pull*), failed to find an agent spatial bias or a verb directionality effect testing both Arabic and English speakers. It is notable also that Chatterjee's experiments employed a rather low *n* (12) of verbs, leaving open the possibility that this effect is driven by an idiosyncratic group of highly imageable verbs. Indeed, in their statistics, only participants were used as random effects. Another problem is that these studies all employed methods involving either scene recognition (i.e., sentence-picture matching) or production (i.e., drawing), making it possible that language comprehenders do not automatically form these spatial representations, but rather only do so when the task involves explicitly relating language to visual images, much in the same vein as what has been shown with tracking spatial relations in the mental model.

Thus, there appears to be some controversy about the potential connection between language and space, especially in representing transitive actions. Nevertheless, cross-study differences warrant further research to explore this possibility. Additionally, the potential involvement of the left temporo-parieto-occipital junction in this left-to-right preference raises the possibility that handedness and language lateralization may be implicated. In any case, the findings reviewed above would lead to interesting predictions about how language interacts with manual movement, processing that is highly dependent both on neural lateralization and on the representation of space. If language does indeed involve spatial processing to such a large extent as is suggested here, then language and hand should be similarly convolved.

Section 1.8 – Hand-space interactions

Given that there are so many different frames of reference to use when describing space, it may not be surprising to learn that multiple spatial frames can be measured at a neural level. One such spatial frame centers on the hand, essentially a tool that allows humans to manipulate objects in space. Indeed, our perception of space is biased by the capabilities of our hands. An example of this is the concept of affordances (Gibson, 1979), i.e., the qualities of objects that define how we interact with them. For example, scissors afford cutting, a coffee mug affords grabbing, etc. In grasping a tool, the tool becomes a kind of extension of the body. This concept of extension is so powerful that it can be measured at a neuroanatomical level. For example, the primate parietal cortex is involved in creating spatial reference frames (Culham & Kanwisher, 2001), which are defined according to specific body parts that may interact with these reference frames, thus guiding behavior. More specifically, the intraparietal sulcus can be divided into regions of perioral, peripersonal, and extrapersonal space (Iriki, Tanaka, & Iwamura, 1996; Colby & Goldberg, 1999). Peripersonal space is defined by what the hand can reach, and thus the location of an apple within arm-reach of a monkey would be coded within these peripersonal spatial region (activating areas within the anterior portion of the intraparietal sulcus). But if the apple is moved out of reach, it would be coded in extrapersonal space, i.e. regions of space beyond manipulation (activating medial intraparietal sulcus). However, if the monkey picks up a mechanical grabber, extending its reach, the apple that was once in extrapersonal space evokes responses in the anterior intraparietal sulcus. In humans this phenomenon is evidenced by the fact that hemispatial neglect can occur selectively for near- and far-space (Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998) and that left side neglect can be mitigated by crossing hands Aglioti, Smania, & Peru, 1999). Thus, the parietal regions that are responsible for spatial processing treat the hand as a tool, and flexibly code stimuli in these regions based on their potential for interaction. This makes the hand a crucial part of our understanding of space, and consequently our understanding of language.

Another important aspect of hand use worth considering is the Simon effect, originally reported in Simon and Rudell (1967) and subsequently replicated and extended by numerous other researchers (e.g., Iani et al., 2009; Iani et al., 2011; Pellicano et al., 2010; Rubichi & Nicoletti, 2006; Simon, 1969; Simon & Small, 1969; Urcuioli, Vu, & Proctor, 2005, Vallesi et al., 2005; Wühr, 2006; Wühr & Ansorge, 2005). The basic effect is that when a response and stimulus correspond in location (e.g., on the left side of the body), responses will be facilitated, even when location is an irrelevant task dimension (see Figure 1.3 for details). A potential explanation for the Simon effect relates to the concept of affordances and peripersonal space. Not only are neural structures that control the movement of body parts located in the contralateral hemisphere of the brain, space is also represented in this manner (e.g., Ivry, 1998). Thus, responding to a stimulus located in the ipsilateral hemisphere will be more efficiently handled by direct intrahemispheric connections to frontal motor networks, as opposed to contrahemispheric responses. However, certain aspects of the effect do not easily coincide with this explanation, as symbolic aspects of stimuli can similarly prime responding. For example: high and low tones prime responses along the vertical dimension (Mudd, 1963); left and right arrows prime left and right responding respectively (Arend & Wandmacher, 1987); and the

SNARC and STEARC effects mentioned previously may also be considered to be more complex instantiations of the Simon effect (Hubbard et al., 2005).

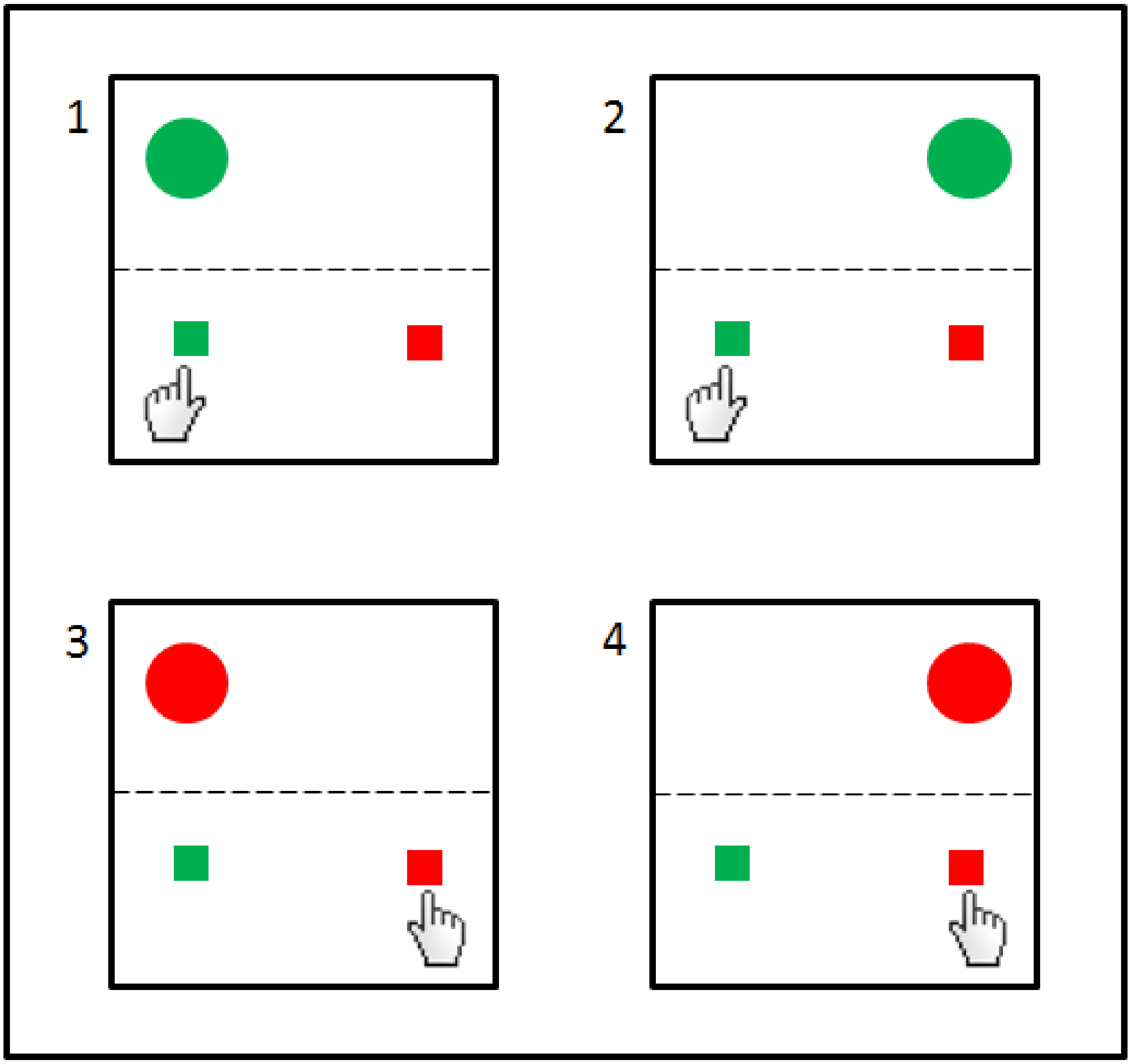


Figure 1.3. The Simon effect. Each panel is divided into stimulus displays (tops) and response panels (bottoms). In this task (a typical Simon task) participants are instructed to respond with the left button when they see a green circle and to press the right button when they see a red circle. In addition to this task-relevant feature, location of response button and stimulus will either match or mismatch. Response facilitation occurs when the location of stimulus and response correspond, such that faster responses will occur on trial 1 and trial 4, but not on 2 or 3.

Rubichi & Nicoletti (2006), noticed that the Simon effects reported in the literature tended to be lopsided—there was less of an effect on the left side of space than on the right. They wondered if this might be an effect of handedness, and investigated this question using two groups—left- and right-handers—first, in a normal design and then in a cross-handed design. They found that right-handers responded faster when the SR corresponded on the right than when SR correspondence occurred on the left, and the opposite was true for left-handers. However, when participants performed the task with crossed hands, the effect transferred over to the opposite (now the dominant-hand-controlled) side of space. Along with Culham & Kanwisher's claims, these results seem to indicate that our spatial attention is guided by our handedness, echoing Gibson (1979) and Glenberg's (1997) claims that the purpose of perception is action. Thus, we are more attuned and sensitive to areas of space that are easier to interact with (i.e., the right side of space for right-handers and the left side of space for left-handers).

Other studies have shown how the hands can induce or modulate spatial processes. For example, Gozli, Ardron, and Pratt (2014) showed that the content of information in near-hand space is processed differently than that in far-hand space. Specifically, objects in near-hand space (i.e., being directly held or manipulated) activate magnocellular visual pathways to a greater extent than do objects in far-hand space, which in turn activate parvocellular pathways, the result being that visuospatial features become bound to objects in far-hand space but not in near-hand space (Gozli, West, & Pratt, 2012; Gozli, Ardron, & Pratt, 2014). Other studies have found that responses are made faster towards cues that appear near the hand (Reed, Grubb, & Steele, 2006), and even that semantic judgements are less accurate in proximal hand space (Davoli et al., 2010). This latter finding suggests an intriguing connection between language and hand, more of which we will explore next.

Section 1.9 – Language-hand interactions

Throughout this general introduction we have frequently encountered areas where the hand and language interact. The first (and most obvious) relationship is in sign language, where the hands take over the duties of speech. Then again, we saw that the embodied cognition literature places a strong emphasis on the relation between action and understanding, motor processing and language. Also, the MARC effect is observed when the linguistic markedness of a stimulus matches that of the response hand (i.e., left or right). The hand, as one of our primary tools for interacting with the world, is naturally focal among these action-motor processes. In addition, the interaction between handedness and writing technology may have influenced the skewed distribution of writing direction and possibly even event processing. Finally, as we saw in the previous section, the hand guides spatial attention, which can have consequences in language processing. In this final section, I will explore a few of the remaining relevant interactions between language and hand.

Speech and motor development

Before uttering their first words, infants will invariably pass through a stage of babbling, usually starting between 6 to 8 months, regardless of whether or not they receive any speech input (Lenneberg, 1967). This is even the case for deaf children, although their babbling is typically delayed and impoverished in regards to hearing children (Oller & Eilers, 1984). In addition to vocal babbling, all children pass through a stage of manual babbling around the same time of life, though some researchers have argued that this stage begins earlier than vocal babbling (e.g., Petitto & Marentette, 1991). Meier and Willerman (1995) showed that both hearing and deaf children produce roughly the same amount of manual gestures during this babbling stage, but that the quality of the deaf children's gestures are more sign-like and complex, in much the same way that the vocal babbling of hearing children is more complex (containing more frequently produced and different types of consonants) than deaf children's. At 12 months of age both hearing and deaf infants have a larger gestural than speech vocabulary (Volterra & Iverson, 1995), and at 16 months infants interact more in the gestural than in the speech modality. Feedback (both sensorimotor and social) is an important factor in linguistic development, which is why eventually deaf children's vocal babbling declines and then ceases altogether, whereas their manual gesturing develops into full-formed signs. This feedback model of babbling also explains why manual babbling emerges earlier than speech, as Lecours (1975) showed that visual pathways become myelinated earlier in life than auditory pathways, thus improving the quality of the visual feedback of motor movements if they are made within the visual field. As the speech of hearing children becomes more complex, the amount of gestural use plateaus and drops away over the course of development, falling back into its assistive role in language production. Meanwhile, the prelinguistic gesture of deaf children becomes more and more complex until it reaches the status of sign language. One might ask if sign languages have the equivalent of the gestures that accompany spoken languages, and in some sense they do, as orofacial gestures, eye gaze, and head movements are used to complement signing, conveying emotion and negation, marking questions (Lillo-Martin, 1995), and indicating frame of reference (Poulin & Miller, 1995). In addition to gesture as a product of manual babbling, both hearing and deaf children also likely acquire a basic vocabulary of motor schemata during this period (i.e., motor components that can be combined to create routines such as manipulation, prehension, and tearing, and which involve prefrontal hand areas and visually-guided motor areas in the intraparietal sulcus; Jeannerod et al., 1995). An ontogeny-as-phylogeny view of development (Nelson, 1996) would seem to suggest that this early stage of robust manual gesturing that all humans pass through points towards some earlier stage in species development when gesturing was a more crucial method of communication (Condillac, 1973; Corballis, 2002; Corballis, 2010; Rizzolatti & Arbib, 1998).

Gesture

As I have already mentioned, as the hearing human develops, manual gesturing becomes relegated to the role of speech accompaniment. While gestures may not seem all that crucial to language, they reveal much about ongoing spoken language, and interact with linguistic processes in important ways. McNeil and Pedelty (1995) identify four different types of co-speech gestures: iconic, metaphoric, beat, and deictic (this excludes the class of gestures known as emblems, which are conventionalized and can be used to replace speech, e.g., *thumbs up*; Rauscher, Krauss, & Chen, 1996). These various types of gesture serve different purposes: iconic gestures are used to describe concrete things or events; metaphoric gestures are used to convey abstract concepts; beat gestures mark linguistic boundaries, whether at the syntactic- or discourse-level; and deictic gestures are used to point to various locations as a means of referring to entities in a discourse. All of these types of gesture assist in both the production and comprehension of speech.

Iconic and metaphoric gestures (sometimes referred to as lexical gestures) tend to occur during or before lexical access, their duration reflecting the amount of time it takes to access the word concurrently being produced. Anomic patients tend to produce many more of these lexical gestures than healthy controls (Krauss, 1998), an indication perhaps of difficulty with lexical access. People tend to use more gestures when discussing concrete terms, as opposed to abstract ones (Krauss, 1998), and when participants are prevented from gesturing, they are more disfluent than when they can freely gesture (Rauscher, Krauss, & Chen, 1996). The purpose of iconic gestures has been proposed to be related to the sensorimotor grounding of language, namely that by producing the actions or tracing the visual contours of the thing being described, sensorimotor regions coding these actions or objects become activated, facilitating word finding (Krauss & Hadar, 1999). Right handers (with left-lateralized language) show a preference for right handed gesture, unless talking about abstract or metaphorical concepts, in which case the right-handed bias is greatly reduced in favor of the left hand (Kita, de Condappa, & Mohr, 2007), reflecting greater involvement of the RH during metaphor production than non-metaphoric production.

On the comprehension side of linguistic processing, beat gestures have been shown to aid in the analysis of syntactically ambiguous sentences. For example, Holle et al. (2012) showed with German-speaking participants that a beat gesture timed with the subject of a sentence in which thematic role assignment is ambiguous leads to a reduction of the P600 effect known to reflect difficulty with syntactic parsing (Coulson, King, & Kutas, 1998). In fact, in Holle et al.'s study gesture was more effective at disambiguating the sentence's agent than prosodic markers. In some ways, this mirrors ASL's use of spatial markers in verb agreement, indicating the agent at the beginning of a signed verb's trajectory (Emmorey, 1999). This could either be considered a type of syntactic gesture or a marker of discourse salience. Similar to beat gestures, iconic and metaphoric gestures also facilitate comprehension. Jamalian and Tversky (2012) showed that the type of gesture (linear vs. circular) that accompanies temporal statements influences how comprehenders will think about time, building either a cyclical or linear representation of events. Özyürek, Willems, Kita, & Hagoort (2007) found that when co-speech iconic gestures mismatched accompanying verbs, there was an N400 effect, an ERP component associated with detecting semantic anomalies, suggesting that comprehenders use visual cues from the speaker to facilitate comprehension. Pointing also aids in comprehension. Children as young as 3 years old are able to interpret the combination of pointing and indirect requests, for example pointing at a pen and saying "I need to write something down" (Kelly et al., 2002). In addition, Kalagher and Yu (2006) showed that deictic pointing facilitates word learning, finding that when parents pointed to different objects concurrently described during a narration, children were more likely to retain newly acquired vocabulary words.

Another point about gesturing connects the discussion so far with that of verb directionality. McNeil and Pedelty (1995) describe a patient, NG, who was commisurotomized at the age of 30. When they tested her ability to perform co-speech gestures at the age of 57, they found her primarily making right-handed representational gestures (i.e., pointing and iconic) in the right side of space. In some of her gestures she traced the paths of moving objects (her task was to watch cartoons and describe what she had seen). Whenever NG was describing an object with a right-to-left trajectory, she would reverse it and describe a left-to-right trajectory. This recalls the findings of Chatterjee and colleagues (Chatterjee, 2001; Chatterjee et al., 1995; Chatterjee, Southwood, & Basilico, 1999; Maas & Russo, 2003) that healthy adults and aphasics tend to describe action moving in a left-to-right manner or make faster judgments about such actions. It would seem in the case of NG that, only having access to the LH in order to describe what she had seen, she could only access the left-to-right trajectory processing regions in the left occipitotemporal regions. In addition, her linguistic utterances would seem to be organized in the basic agent-on-the-left manner.

Finally, several studies have looked at the relationship between pointing and anaphora. These two concepts are tightly linked, as anaphora in sign language (and sometimes in co-speech gesture) is accomplished through pointing, and pointing gestures are among the first to develop in infancy (which Vygotsky proposed to be developed out of abortive grasps; 1934). Hemforth et al. (2012) and Konieczny et al. (2010) investigated the relationship between anaphoric processing and pointing gestures in both French and German. Participants read two-sentence discourses, the first sentence referring to two characters, one in subject and the other in object position. The second sentence referred to either one of those entities through the use of an unambiguous pronoun. Participants had to judge the plausibility of the sentences by pressing buttons on a response box. The response box was designed in such a way that participants had to move their hand left or right to make a judgment, employing a design similar to that used by Glenberg and Kaschak (2002). Konieczny and Hemforth both found that judgments following reference to the subject of the previous sentence were faster if made with a leftward motion of the hand, while judgments following reference to the object of the previous sentence were faster with a rightward one. They took these results to be evidence for the grounding of anaphora in pointing gestures. This may stem naturally from the tight link between hand and eye movements, and the setting of eye placement that occurs during reading. What this means is that language users track entities in a discourse through the use of manuospatial resources. Discourse entities are stored in a virtual space, roughly with subjects on the left and objects on the right. Pointing is facilitated if pointing direction and location in virtual space are compatible. Whether this occurs when reading space is better controlled (word-by-word presentation in the center of the screen) or through using audio instead of text, is not known.

Homesign

A final point to consider is the phenomenon of homesign, a gestural system developed by deaf individuals who grow up with no exposure to full-fledged sign languages. Although these children have no exposure to languages with syntax, they nevertheless develop a kind of rudimentary syntax with nouns and verbs and rough rules that tend to correspond with SOV ordering for transitive sentences and SV for intransitive sentences (Goldin-Meadow, 2005). In general though, homesigners, when dealing with complex sentences (i.e., sentences involving more than one actor), tend to omit the subjects of transitive structures and the subjects and direct objects of ditransitive or place verbs (e.g., *give mother/mother give* or *put table/table put*). Thus, although these deaf children tend to omit entities from their sentences, they maintain a bare predicate frame containing the essential entities demanded by the verb. In fact, the linguistic behavior of homesigners closely mirrors the case marking patterns of speakers of ergative languages (i.e., languages that share a case for the actor of an intransitive sentence and the object of a transitive sentence) as opposed to nominative-accusative systems in which subjects of transitive and intransitive sentences share case marking. Interestingly, although ergative languages are somewhat uncommon, Fillmore (1968) cites evidence suggesting that English and a number of other modern languages evolved out of ergative case-marking systems. Note also that when all of the actors of a sentence are present in a sentence, the ordering SOV is the most typical word order among the languages of the world (see Table 1.1).

One might argue that the intransitive actor (i.e., ***he*** *ran*) and the transitive patient (i.e., *I hit* ***him***) may be more likely to be less salient discourse entities than the transitive actor (i.e., ***I*** *hit him*), and thus homesigners are not marking thematic role as such but rather signing newer or less salient information. However, Goldin-Meadow (2005) showed that these entities tend to be signed whether their status in the discourse is old or new. Thus, what is more likely is that the relationship between an intransitive actor and a transitive patient is more similar than the relationship between transitive and intransitive actors. In other words, what is important in these sentences is not to mark who is doing what, but rather who or what is changing or being affected. In an intransitive sentence, the actor is typically undergoing some kind of change of state, while in a transitive structure the patient is undergoing a change of state brought about by the actor.

Interestingly, some of the homesigners Goldin-Meadow studied differentiated between nouns and verbs through the use of spatial inflection on the verbs they produced. For example, they would make the sign for *twist* near a jar, indicating that the jar is the patient of the action *twist*. What is striking about this method of inflection is that it appears to be a spatial manifestation of the second most common characteristics among word ordering in the languages of the world: verb-object contiguity (Greenberg, 1963; Kemmerer, 2012; Tomlin, 1986). This tight link between the action and the patient of that action—i.e., the temporospatial bonding found in the majority of the world's languages and these spontaneously formed homesign systems—suggest that syntax (and word order) developed out of a very basic understanding of action scenarios. Additionally, syntax attempts to represent these relations in an iconic fashion through temporospatial proximity.

Section 1.10 – Conclusions and proposed experiments

At the beginning of the introduction, I outlined the main purpose of this dissertation. To repeat: what is the relationship between the syntactic concept of transitivity, space, and hand? In order to set up the motivation for the experiments to follow I described research lines spanning a number of disciplines, and we have seen so far that language, space, and hand do interact in numerous ways. The clearest connections between language and space are in spatial descriptions, signed languages, and the maintenance of entities in the mental model. The hand biases spatial attention, and spatial codes of stimuli affect manual responding. Between hand and language, again sign languages and homesigns are indisputably important, but so too are co-speech gestures. Perhaps related to gesturing, the sensorimotor grounding of language also tightens the connection between these three modes. However, these areas can probably be categorized as "explicit" connections. There are robust bodies of research to back up the claims I have just listed. In the discussion I also covered a number of more speculative connections, namely in the sections on word order, writing direction, and verb directionality. These claims are as follows: the word order biases among languages of the world are a result of the cognitive preference to iconically retain the order of events as they occur in the world via the ordering of linguistic code; writing direction biases among the world's writing systems also (though more speculatively) reflect a form of event iconicity; this iconicity is a function of the relatively greater ease in processing or preference towards left-to-right actions. Aspects of these claims are essentially unanswerable, as they are tied into complicated social histories stretching back thousands of years till the dawn of human interaction, and in these cases speculation will have to suffice. Nevertheless, certain questions can be answered empirically. Is syntax embodied in space and hand? Is this embodiment similar to or distinct from what has been found in the magnitude-space literature? Is word order an important factor in embodied syntax? Given the importance of the hand in processing space, how does it modulate the proposed syntax-space connection? How is the syntax-space connection related to the spatial effects that have been observed in scene recognition and production studies?

The rest of this dissertation addresses these questions. Experiments 1 and 2 introduce a new paradigm aiming to measure and (to preview) find support for the syntax-space effect. Experiment 3 will examine whether the effect is specific to the actors (i.e., agents and patients) of a sentence and how the hand may be important in producing the effect. Experiment 4 tests whether or not the previous studies are related to the SNARC effect. Experiment 5 asks whether the syntax-space effect is observable in the auditory domain. Experiment 6 looks at the importance of word order and the concept of agency in producing the effect. Experiment 7 addresses the question of whether the hand is crucial to the syntax-space effect. Experiment 8 directly tests the effect of hand positioning on the syntax-space effect. Experiment 9 moves the basic paradigm into scene processing, to see if the effect is connected to processing images. Finally, Experiment 10 tests to see if the effect exists without language processing involved, and how this might change across two different languages groups. After reporting these experiments and their results, I will then discuss the findings in light of the overall connections between language, space, and hand as has been covered in this introduction.

CHAPTER 2

EXPERIMENT 1

Experiment 1 (E1) was designed to extend findings from other research lines and establish them in a word-by-word reading paradigm. My main interest was to investigate the possible spatial bias of different parts of transitive sentences; namely, the subject and object. Specifically, would there be facilitation in identifying the subject of a sentence when it appeared on the left side of space and identifying the object of a sentence when it appeared on the right. For the purpose of testing this hypothesis, I developed a design inspired by techniques used in the Simon and SNARC effects literature (Hubbard et al., 2005; Simon, 1969), using a button box with left- and right-lateralized buttons, and with participants responding to probes appearing in SR matching or mismatching regions of space.

Methods

Participants

Forty-eight participants (45 female, 3 male, *M* age = 20.5) took part in this study for extra credit towards a psychology class. All participants were right-handed (self-reported), native speakers of English with normal or corrected-to-normal visual acuity (self-reported). Participants gave their informed consent to participate in this research under the guidelines of the University of South Carolina Institutional Review Board (USC IRB).

Procedure

Eighty transitive sentences were created[5], each consisting of two male or female characters, with an equal number of all-female or all-male items. Sentences were an average of 7.1 words long (range: 5-10). I equated word length of subject (M length = 5.41) and object (M length = 5.58) names within sentence ($t = 0.7$, $p > 0.05$). Sentences were presented one word at a time in the center of a computer monitor. Each trial began with a fixation cross lasting one second. This was followed by the sentence, 500 ms for each word. Following the final word another fixation cross was presented for 1500 ms. After this a probe (either the subject or object of the previous sentence) appeared on either the left or right side of the screen. For half the trials participants were instructed to respond on a PST Serial Response Box with a left button press when encountering the subject and a right button press for the object, and on the other half of the trials button assignment was switched. Participants had 4500 ms to respond to the probe before advancing to the next trial. Failures to respond were coded as incorrect. Each block began with 8 practice trials presenting items in all possible conditions (Male vs. Female, Subject vs. Object, Left vs. Right side presentation). Participants could only advance into the experimental block after achieving at least 75% accuracy. Button assignment order was counterbalanced across subjects. Item presentation within block was randomized (see Figure 2.1 for schematic representation of a sample trial and Table A.1 in the Appendix for all items used in this experiment).

[5] Note that the original item set from E1 and E2 contained several (8) verbs that were not strictly transitive. Some of these were phrasal or ditransitive verbs. In order to reduce variability, these were removed before conducting analyses.

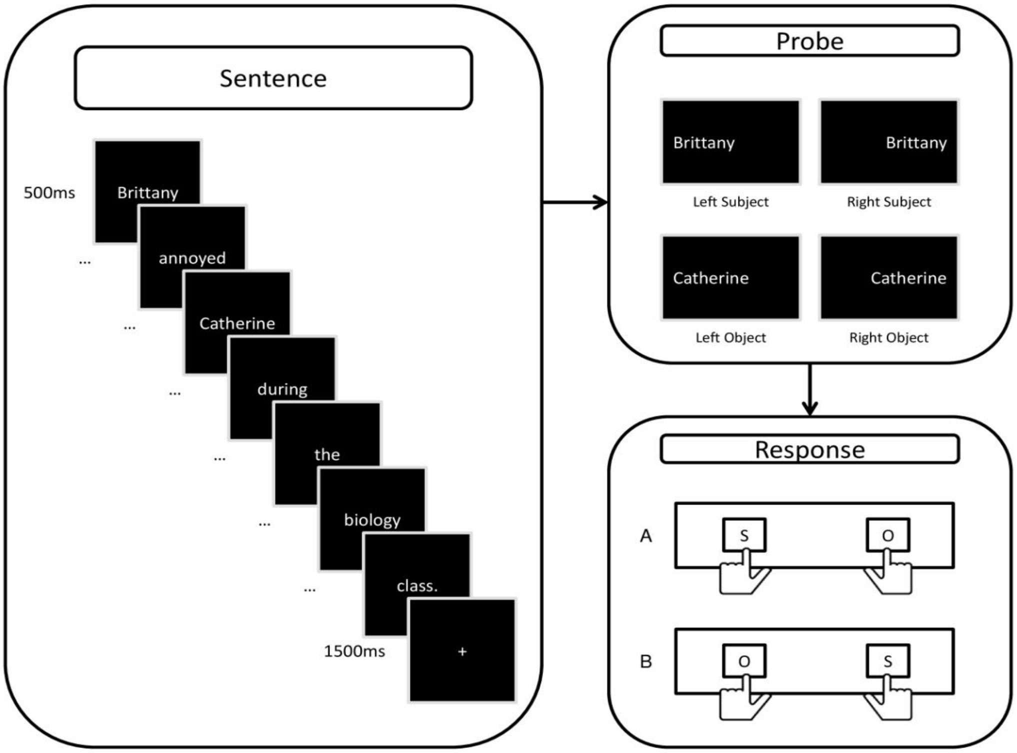


Figure 2.1. Schematic of sample trial from Experiment 1.

Results

For this and subsequent experiments I am primarily interested in RTs to correct probe recognition. Therefore, before conducting data analyses all incorrect responses were removed from the dataset (21.18%)[6]. In addition, I reasoned that responses faster than 300 ms did not reflect semantic judgments (i.e., blind reactions, not responses), while responses slower than 3000 ms reflected failures to attend to the task. Thus, responses that did not fall in between these limits were removed from the dataset as well

[6] I tested for differences between conditions in error rates, but there were no significant effects (*p*'s > 0.05) For the sake of brevity, I do not report those analyses further.

(0.19%). In all, then, 21.37% of responses were removed, and log-transformed RTs were analyzed.

Data analyses were conducted in the lme4 package (Bates, Maechler, and Bolker, 2011) in R (v.3.1.1; R Development Core Team, 2014), using mixed-effects modeling with stimulus Side (Left vs. Right), response Hand (LHand vs. RHand), and Word type (Subject vs. Object) as fixed effects, as well as all possible interactions between the three factors, and random intercepts and slopes both by-participants and by-items (Baayen, Davidson, and Bates, 2008; Barr, Levy, Scheepers, & Tily, 2013). I compared the full model with a model that included all two-way interactions and main effects and found that the full model was a better fit, $\chi^2(1) = 7.82$, $p = 0.005$. Full model results are reported in Table 2.1 and graphically in Figure 2.2.

Table 2.1 Fixed effects for the max model in Experiment 1.

Coefficient Estimates - Baseline levels are Object, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.655	0.032	206.382	0.001***
β_1	Subject	-0.1	0.018	-5.661	0.001***
β_2	RSide	-0.00006	0.018	-0.003	=0.997
β_3	RHand	-0.054	0.018	-3.061	=0.002**
β_4	Subject*RSide	0.046	0.025	1.832	=0.067 **.**
β_5	Subject*RHand	0.113	0.025	4.534	0.001***
β_6	RSide*RHand	0.014	0.025	0.546	=0.585
β_7	Subject*RSide*RHand	-0.099	0.035	-2.798	=0.005**

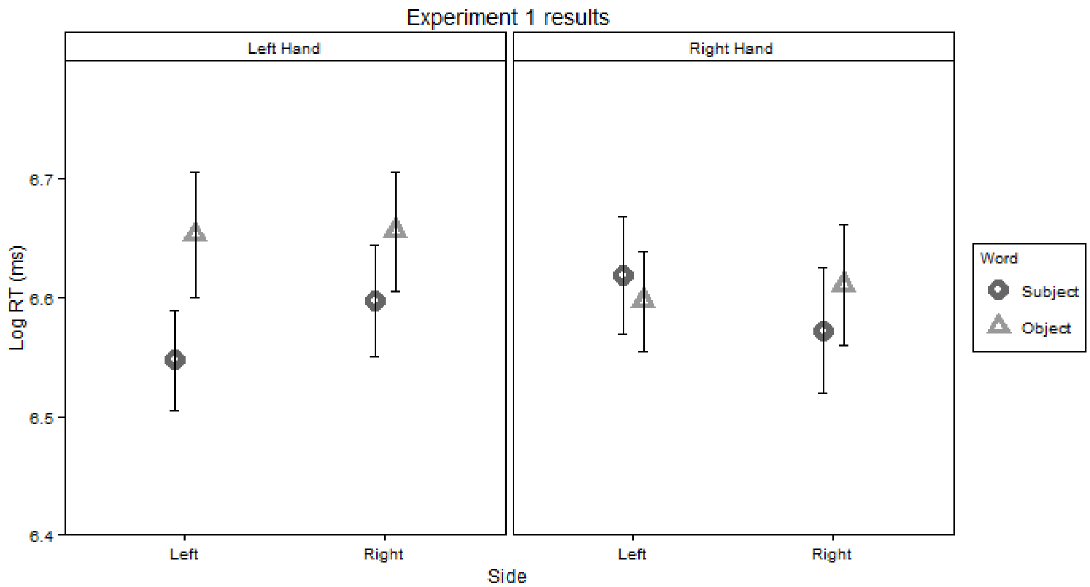


Figure 2.2. Graphical results of Experiment 1, showing the three-way interaction between Side, Hand, and Word. Log-transformed RTs on the y-axis. Bars represent SE.

In order to get a better understanding of the interaction, I ran a series of post-hoc comparisons, using a Bonferroni *p* value adjustment. Due to the large number of possible contrasts, I only report in the text those that were either or theoretical interest (see Table 2.2 for all contrasts and statistical details). First, there was a benefit of responding to Subjects on the Left using the LHand as opposed to Objects on the Left with the LHand. Additionally, Subject responses on the Left with LHand were faster than Object responses on the Right with the LHand. Subject responses on the Left with the LHand were faster than Subject responses on the Left with the RHand. Subjects on the Left with the LHand were also faster than Objects on the Right with the RHand. Also, Subjects on the Right with the RHand were faster than Objects on the Left with the LHand.

Table 2.2. Experiment 1 pairwise comparisons for the three-way interaction between Side (Left-L, Right-R), Word (Subject-Sub, Object-Ob), and Hand (Right Hand-RH, Left Hand-LH).

Condition	Stat	LSubH	LObRH	LSubRH	RObLH	RSubLH	RObRH	RSubRH
LObLH	*Est.*	.1	.054	.041	<.001	.054	.041	.081
	SE	.018	.018	.018	.018	.018	.018	.018
	t	5.65	3.06	2.29	.003	3.05	2.29	4.51
	p	<.001	.06	.62	1	.06	.62	<.001
LSubLH	*Est.*		-.046	-.059	-.1	-.046	-.06	-.02
	SE		.018	.018	.018	.018	.018	.018
	t		-2.61	-3.33	-5.66	-2.58	-3.37	-1.11
	p		.26	.02	<.001	.28	.02	1
LObRH	*Est.*			-.013	.054	<-.001	-.014	.026
	SE			.018	.018	.018	.018	.018
	t			-.75	3.06	-.01	-.77	1.49
	p			1	.06	1	1	1
LSubRH	*Est.*				.041	-.013	<-.001	.04
	SE				.018	.018	.018	.018
	t				2.29	-.75	-.02	2.23
	p				.62	1	1	.72
RObLH	*Est.*					.054	.041	.08
	SE					.018	.018	.018
	t					3.05	2.29	4.52
	p					.06	.62	<.001
RSubLH	*Est.*						-.014	.026
	SE						.018	.018
	t						-.78	1.47
	p						1	1
RObRH	*Est.*							.04
	SE							.018
	t							2.25
	p							.68

Finally, in addition to the post-hoc comparisons reported above, I tested the effect of Subject- and Objecthood on response Side separately for the LHand and RHand, calculating the difference in Object and Subject responses for each of the four possible Side x Hand conditions (i.e., calculating separately the two data points of each column in

Figure 2.2). Then I ran two comparisons between Left to Right Side responses for the difference scores on the LHand and then again for the RHand. On the LHand, this difference between Object and Subject times was significant, Left Side $M = 0.052$, $SE = 0.015$, Right Side, $M = 0.022$, $SE = 0.014$, $t(47) = 2.4$, $p = 0.02$; however, on the RHand this difference was only marginally significant, Left Side $M = -0.01$, $SE = 0.014$, Right Side, $M = 0.018$, $SE = 0.017$, $t(47) = 1.95$, $p = 0.06$. This suggests that the LHand may be more sensitive to the Word x Side interaction.

Discussion

The results from E1 say several things. First there appears to be some penalty associated with left hand object responses, whereas subjects fare equally well on either hand. This basic effect appears to also be driving the results of the three-way interaction, in which there was no difference between objects and subjects on the right side and the right hand, but large differences when these responses were shifted to the left side and left hand. In addition, difference score comparisons showed that for left hand responses, there is an interaction between the type of word and the side of space, while on the right hand this effect either diminishes or disappears outright.

The results are thus encouraging, showing that there does indeed appear to be an underlying spatial component to transitive sentences (and potentially varying across the hand). It is, however, also possible that these results are merely an effect of the task. Participants were explicitly asked to map subjects and objects onto either the left or right hand. Manual responses are known to interact with the orientation of stimuli (Simon, 1969). Therefore, it seems plausible that the manual effect is interacting with the spatial effect of the words and not that it is central to the syntax-space effect. It seems then too premature to draw any strong conclusions from the results of this experiment. It is crucial to test whether there is still a spatial preference to the entities of transitive structures when they are not explicitly mapped onto alternate hands. I address this issue in Experiment 2.

Chapter 3

Experiment 2

In E1 I showed preliminary evidence for a spatial bias of transitive structures. In Experiment 2 (E2) I tested whether this effect can be observed when no direct attention is drawn to the fact that the probe words are the subjects and objects of the previously read sentences. This was accomplished by asking participants to judge the gender of the name probes of characters from the priming sentences and keeping all other aspects of the experimental design the same.

Methods

Participants

Forty right-handed participants (29 female, 11 male, *M* age = 20.7) took part in this study for extra credit towards a psychology class. All participants were native speakers of English with normal or corrected-to-normal visual acuity (self-reported). Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

The procedure of this experiment was very similar to that of E1. The main difference was that participants were asked to read the prime sentences and then judge the gender of the probe words. In addition, the items were altered such that each sentence contained both a male and female character, with the gender of subjects and objects counterbalanced across items. Also, participants were told that following the computer portion of the test, there would be a test asking them about specific items from the experiment to encourage participants to read the sentences for comprehension and not just respond to the probe words. Half of the participants (group A) responded to female probes with a left button press and male probes with a right button press (with left and right hands respectively), and the other half (group B) had the opposite button assignment (see Figure 3.1 for a graphical schematic of the experiment and Table A.2 in the Appendix for a full list of experimental items).

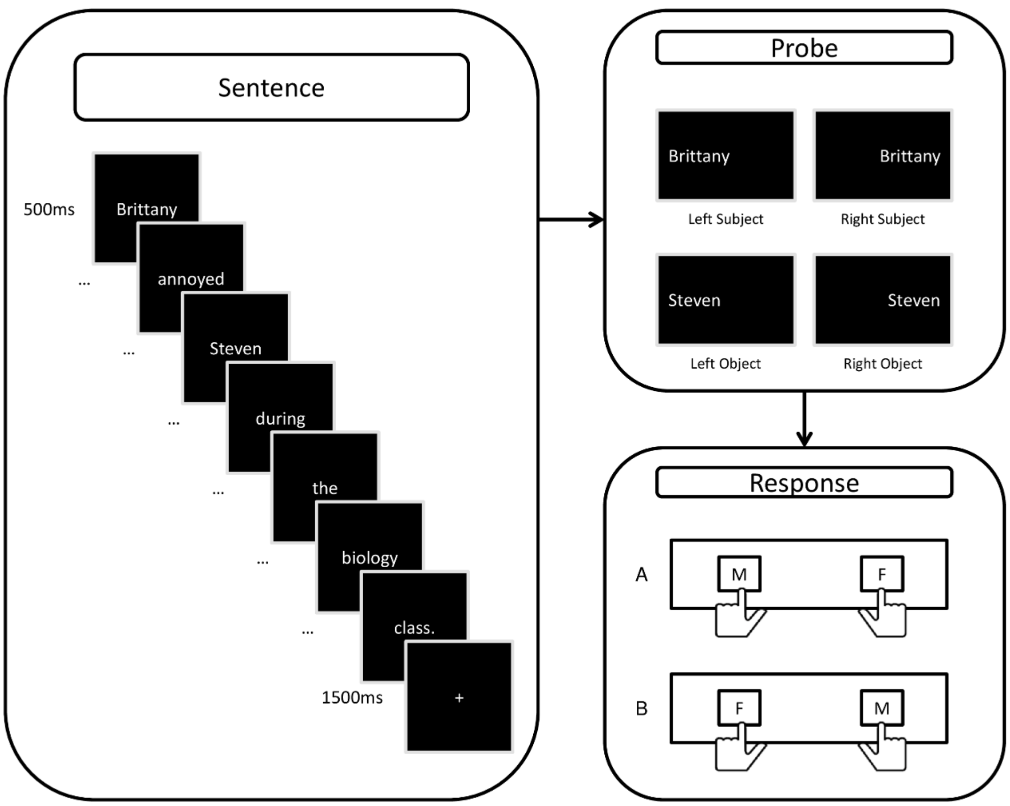


Figure 3.1. Schematic of sample trial from Experiment 2.

Results

All analyses were conducted as in E1, using mixed-effects modeling with stimulus Side (Left vs. Right), response Hand (LHand vs. RHand), and Word type (Subject vs. Object) as fixed effects, as well as all possible interactions between the three factors, and random intercepts and slopes both by-participants and by-items (Baayen, Davidson, and Bates, 2008; Barr, Levy, Scheepers, & Tily, 2013). I compared the full model with a model that included all two-way interactions and main effects and found that the full model was a better fit, $\chi^2(1) = 4.9$, $p = 0.03$. Full model results are reported in Table 3.1 and the three-way interaction between Side, Word, and Hand in Figure 3.2.

Table 3.1. Fixed effects for the max model in Experiment 2.

Coefficient Estimates - Baseline levels are Object, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.611	0.024	277.638	0.001***
β_1	Subject	-0.027	0.017	-1.576	=0.116
β_2	RSide	-0.034	0.016	-2.173	=0.03 *
β_3	RHand	-0.007	0.016	-0.47	=0.639
β_4	Subject*RSide	0.069	0.022	3.106	=0.002 **
β_5	Subject*RHand	0.052	0.022	2.316	=0.021 *
β_6	RSide*RHand	0.028	0.022	1.276	=0.202
β_7	Subject*RSide*RHand	-0.07	0.032	-2.216	=0.027 *

In order to get a better understanding of the interaction, I ran a series of post-hoc comparisons, adjusting *p* values using the Bonferroni method. Using this stringent *p* value adjustment, there were no significant contrasts, so I reran the analyses without

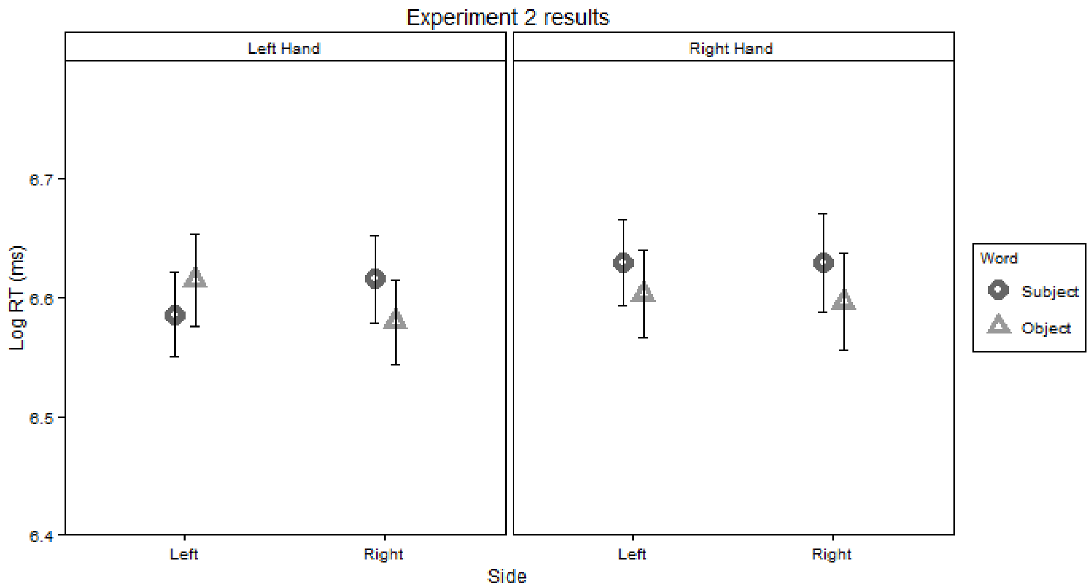


Figure 3.2. Graphical results of Experiment 2, showing the three-way interaction between Side, Word, and Hand. Log-transformed RTs on the y-axis. Bars represent SE.

using such a correction (see Table 3.2 for these uncorrected post-hoc comparison results). There were two comparisons that were significant: for the LHand, Object responses on the Right were faster than Subject responses on the Right, $t(39) = 2.17$, $p = 0.03$; also, Right Object responses on the LHand were faster than Right Object responses on the RHand, $t(39) = 2.48$, $p = 0.01$.

Next, as was done in E1, I calculated difference scores between Object and Subject responses and tested two key comparisons in order to see how the effect changed across response hand (i.e., calculating separately the two data points of each column in Figure 3.2). Then I ran two comparisons between Left to Right Side responses for the difference scores on the LHand and then again for the RHand. On the LHand, this difference between Object and Subject times was significant, Left Side $M = 0.017$, $SE =$

Table 3.2. Experiment 2 pairwise comparisons for the three-way interaction between Side (Left-L, Right-R), Word (Subject-Sub, Object-Ob), and Hand (Right Hand-RH, Left Hand-LH).

Condition	Stat	LSubH	LObRH	LSubRH	RObLH	RSubLH	RObRH	RSubRH
LObLH	*Est.*	.005	.002	-.004	.018	-.013	-.014	.002
	SE	.014	.013	.014	.013	.014	.013	.014
	t	.38	.122	-.3	1.38	-.91	-1.1	.17
	p	.71	.9	.77	.17	.37	.27	.86
LSubLH	*Est.*		-.004	-.009	-.012	-.018	-.019	-.003
	SE		.014	.012	.014	.013	.014	.013
	t		-.27	-.75	-.89	-1.42	-1.38	-.22
	p		.79	.45	.38	.16	.17	.82
LObRH	*Est.*			-.006	-.016	.014	-.016	.001
	SE			.014	.013	.014	.013	.014
	t			-.41	-1.26	1.01	-1.21	.06
	p			.68	.21	.31	.23	.95
LSubRH	*Est.*				-.022	.009	.01	.007
	SE				.014	.013	.014	.013
	t				-1.57	.68	.72	.52
	p				.12	.5	.48	.61
RObLH	*Est.*					-.03	-.032	-.015
	SE					.014	.013	.014
	t					-2.17	-2.48	-1.08
	p					.03	.01	.28
RSubLH	*Est.*						-.001	.015
	SE						.014	.013
	t						-.1	1.18
	p						.92	.24
RObRH	*Est.*							.017
	SE							.014
	t							1.17
	p							.24

0.008, Right Side, M = -0.019, SE = 0.006, $t(39)$ = 3.42, p = 0.001; while on the RHand this difference was not significant, Left Side M = -0.011, SE = 0.008, Right Side, M = -0.012, SE = 0.008, $t(39)$ = 0.188, p = 0.85. This is consistent with the difference score comparisons run in E1.

Discussion

The purpose of E2 was to extend the findings of E1 into a situation where no direct attention is being attracted to the subject- or object-hood of the probe words. While I found an effect similar to what was found in E1, the post-hoc comparisons that were significant were only so without using a correction for multiple comparisons. This is perhaps not too surprising, given the fact that during the computer portion of this task participants did not actually have to pay attention to the sentences (i.e., they could judge the gender of the probes without needing to know the context). Thus, it is likely that their attention was fluctuating during the experiment, with some items not being read carefully, making the data much noisier than in E1.

Despite these weaker results, the three-way interaction reported in E1 and what I found here are very similar in nature. Both suggest a sensitivity of the left hand to this underlying spatial bias of the entities in the transitive structure. Indeed, the difference score comparisons in this experiment showed much more clearly that there is an interaction between syntax and space on the left hand (a finding reminiscent of Zwaan & Yaxley, 2003), while there is no such effect on the right hand. This latter finding is similar to what was found in E1, where the interaction on the right hand was only marginally significant.

Thus, while the findings of E1 and E2 are encouraging, there are a number of issues that remain to be addressed. First, subsequent experiments clearly need a design in which subject- and object-hood are not mapped directly onto the hands, but which also assures participants will attend to all aspects of the stimuli and comprehend the sentences. Second, the syntax-space effect (i.e., the interaction between Word and Side) observed so far may simply be a function of word order in the prime sentences. Subjects occur first, followed by objects, but in the items used here the object was not the final word in the sentence. How would participants fare when responding to the last word in a sentence? Is it the case that they are creating a mental map of the order of words in the sentence? I address the word order, hand mapping, and sentence comprehension problems in Experiment 3.

CHAPTER 4

EXPERIMENT 3

The main purpose of Experiment 3 (E3) was to find out if the syntax-space effect observed so far remains when responding is not lateralized (making the design less similar to what has typically been used in the Simon effect literature). In addition, I compare recognition of subjects and objects to the final word in the sentence. If this effect is driven by serial word order, then the final word should show as strong a right-side bias as the object showed a left side penalty in E1 and a right side advantage in E2. In this task, then, participants judged whether a probe word was in the sentence they had just read or not (a go/no-go task). Finding a syntax-space effect using such a task would provide further evidence that language comprehenders naturally generate spatial schemata when encountering transitive sentences, and that these schemata follow a predictable pattern with the tendency of subjects to be placed to the left of objects.

Methods

Participants

Eighty-one participants (63 female, 18 male, *M* age = 20.1) took part in this study for extra credit towards a psychology class. All participants were right-handed, native speakers of English with normal or corrected-to-normal visual acuity (self-reported). Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

The procedure for this experiment was similar to the previous one with a few alterations. The main alteration is that participants were no longer asked to identify the subject and object of the previously read sentence. Instead, they would read a sentence, encounter a probe, and judge whether the probe word was in the sentence they had just read. Half of the probe words were either the Subject, Verb, Object, or Final word from the sentence they read (Present), and the other half from another item whose probe words were not used in that participant's session (False). Present probes required the participant to press the middle button on the button box. False probes were ignored. Since the number of conditions in this experiment was increased, I doubled the number of items as well. This involved modifying some of the items from E1 and E2 and writing new ones. One quarter of the items had two male characters, one quarter two female, one quarter a male subject and female object, and the final quarter a female subject and a male object (all experimental items can be found in Table A.3 in the Appendix).

The Subjects and Objects in our items were equated for length (Subject $M = 5.34$, range: 3-10; Object $M = 5.36$, range: 3-10; $t(159) = .23$, $p > .05$). No attempt was made to equate the length of the Verbs and Final words with the Subjects and Objects. Final words were an average of 6.29 letters long (range: 3-12), a length significantly longer than Subjects, $t(159) = 4.63$, $p < .001$, and Objects, $t(159) = 4.67$, $p < .001$. I discuss potential implications for this difference (mainly why it is not a concern) in the discussion to this experiment. As I am only interested in comparing the Subject and Object with the Final word, because all of these are nouns and there are baseline differences in reading times between nouns and verbs (especially across hemispheres;

Sereno, 1999), I did not analyze Verb length or any spatial bias in responding to these types of probes. Sentences were an average of 6.37 words in length (range: 5-7).

In addition to altering the probe task, comprehension questions were also added, appearing following one-third of the items. Half of these required a Yes response (i.e., a button press) and the other required a No response (i.e., no button press). The purpose of the comprehension questions was to make sure that participants were not just memorizing the sentences as lists of words and were actually reading to understand the items.

Roughly half of the participants were instructed to respond to probes and comprehension questions using their right hand ($n = 38$), and the rest ($n = 43$) used their left hand. The reason for this manipulation was that the syntax-space effect found in the first experiment seemed dependent on response hand. If this was indeed an essential factor, then only the left hand group should show a spatial bias in responding to probes. If however, the effect from the first experiment was a result of a combination of a syntax-space effect with a task dependency effect (for example, an easier mapping of the Subject onto the left hand), then there may still be a syntax-space effect when the task does not depend on such a word-response hand mapping (see Figure 4.1 for a schematic sample trial).

Results

As I did in E1, before conducting data analyses I removed all incorrect probe responses from the dataset (3.33%), and all trials with incorrect responses to the comprehension question (4.49%). Next, I trimmed out extreme responses faster than 300 ms and slower than 3000 ms (0.29%). In all, then, 8.11% of responses were removed. In

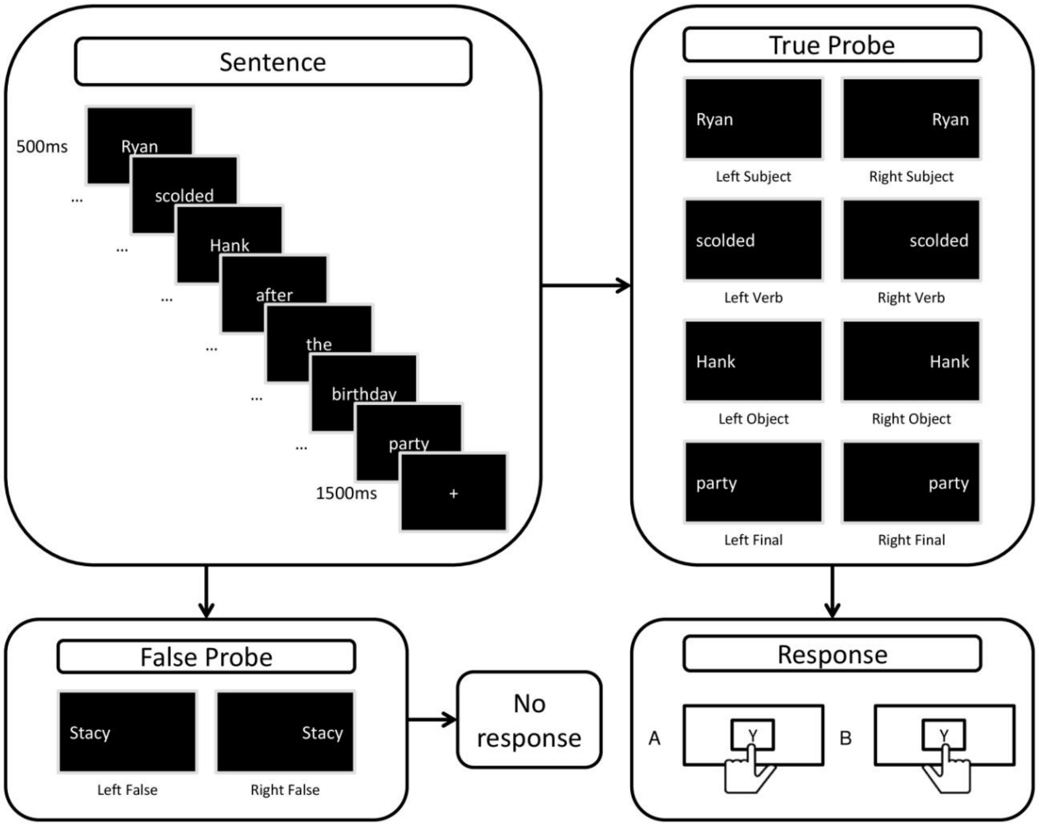


Figure 4.1. Schematic of sample trial from Experiment 3.

addition to this, one participant's data from the left hand group were excluded from the analysis as that participant only achieved around chance on the comprehension questions (57%), while the rest of the participants achieved around 89% accuracy. For the analyses below I report log-transformed RTs as per the previous experiments.

Data analyses followed the same procedure as before, using mixed-effects modeling with stimulus position (Side) with levels Left and Right, between-subjects factor Hand with levels LHand and RHand, and word type (Word) with levels Subject, Object and Final as fixed effects, as well as the interaction between the three factors.

Items and participants were treated as random effects, with the interaction between Word and Side included in the random slope structure (Baayen, Davidson, and Bates, 2008). Full model results are reported in Table 4.1.

Table 4.1. Fixed effects for the max model in Experiment 3.

Coefficient Estimates - Baseline levels are Object, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.694	0.029	230.867	0.001***
β_1	Final	0.007	0.025	0.27	=0.787
β_2	Subject	-0.0002	0.025	-0.007	=0.994
β_3	RSide	-0.047	0.025	-1.852	=0.064 .
β_4	RHand	0.072	0.042	1.726	=0.086 .
β_5	Final*RSide	0.038	0.035	1.091	=0.276
β_6	Subject*RSide	0.095	0.036	2.685	=0.007**
β_7	Final*RHand	-0.013	0.037	-0.346	=0.73
β_8	Subject*RHand	0.038	0.037	1.01	=0.313
β_9	RSide*RHand	0.027	0.036	0.741	=0.459
β_{10}	Final*RSide*RHand	-0.033	0.052	-0.641	=0.521
β_{11}	Subject*RSide*RHand	-0.137	0.052	-2.633	=0.009**

Statistical analyses were conducted by removing coefficient by coefficient in order to find the model of best fit. It was found that removing the three-way interaction between Word, Side, and Hand led to a significant reduction in variance, $\chi^2(2) = 7.47$, $p = 0.02$ (see Figure 4.2).

In order to get a better understanding of the three-way interaction, the data were split into R- and LHand datasets, and analyses were rerun on separate datasets with the

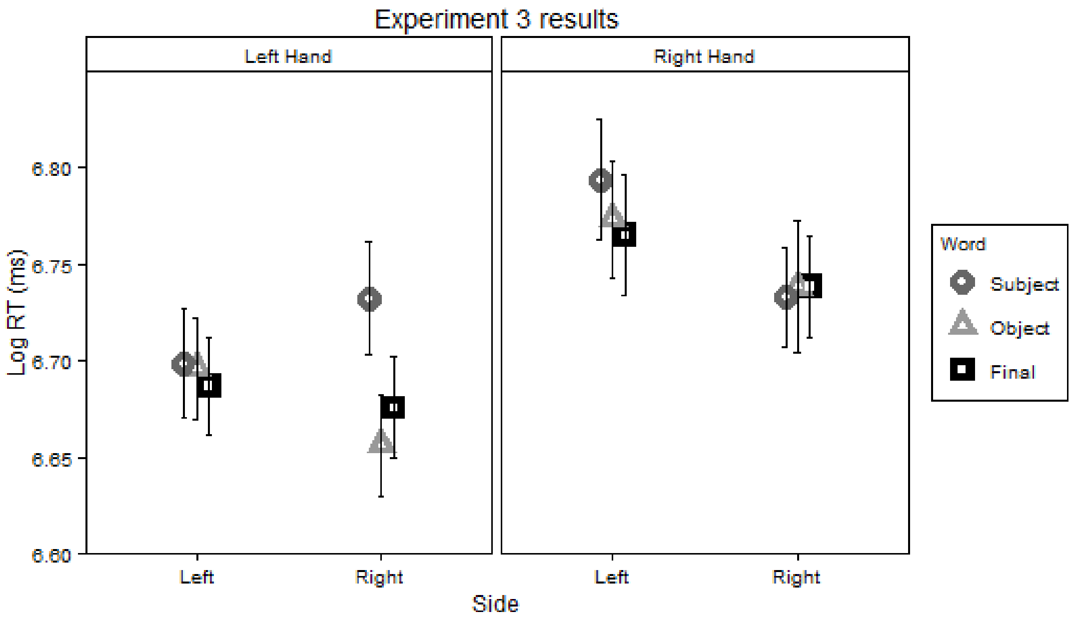


Figure 4.2. Graphical results of Experiment 3, the Side x Word x Hand interaction. Log-transformed RTs on the y-axis. Bars represent SE.

variables Word and Side. For the RHand set, there was no interaction, $\chi^2(2) = 1.29$, $p = 0.53$, nor was there a main effect of Word, $\chi^2(2) = 0.86$, $p = 0.65$, but the main effect of Side was marginally significant, $\chi^2(2) = 3.7$, $p = 0.08$, with a slight advantage for Right Side responses. For the LHand set, the interaction was significant, $\chi^2(2) = 8.72$, $p = 0.01$. Bonferroni-adjusted pairwise comparisons revealed that only one contrast was significant: Right Object responses were faster than Right Subject responses (see Table 4.2 for all contrasts and statistical details).

Discussion

In E3 I addressed several questions: is response laterality necessary to bring out the proposed syntax-space effect and is position in the sentence the only driving factor of

Table 4.2. Experiment 3 pairwise comparisons for the LHand group two-way interaction between Side (Left – L, Right – R) and Word.

Condition	LObject	LSubject	RFinal	RObject	RSubject
LFinal	.007	.009	.008	.051	-.04
	.022	.022	.022	.022	.022
	.31	.412	.385	2.362	-1.811
	1	1	1	.276	1
LObject		.002	.002	.045	-.047
		.023	.023	.023	.023
		.091	.067	1.963	-2.032
		1	1	.75	.637
LSubject			-.001	.043	-.049
			.022	.022	.022
			-.023	1.905	-2.173
			1	.857	.451
RFinal				.043	-.048
				.022	.023
				1.92	-2.134
				.828	.497
RObject					-.091
					.023
					-4.025
					<.001

such an effect? There was a three-way interaction similar to previous experiments, characterized by a syntax-space effect on the left hand but not the right. Given that responses were not lateralized, the left hand effect in this experiment suggests hemispheric processing differences (an issue that will be explored at greater length in E8). Moreover, the spatial effect was associated with subject and object responses and not the final word of the sentence. This latter finding suggests that the syntax-space effect observed so far is not simply an effect of the position of a word in the sentence, but perhaps that it reflects mental model construction biases, where the actors have clear spatial preferences. The final word in the sentence (which in these items were typically temporal or locative expressions) would not show any clear bias because they were integral to the entire scenario and could not easily be assigned to a mental space.

In the Methods section of this experiment I noted that the final words of the sentence were on average longer than both the subjects and objects. In fact, such a difference might have been argued to be problematic. According to the magnitude-space literature, *more* of something produces a greater rightward bias, while *less* of something produces more of a leftward bias. The difference in length of these words therefore might have led some to predict that final words would indeed lead to faster right-side responses (i.e., in the same direction as the position-in-the-sentence hypothesis would predict). Therefore, the fact that there was not such an effect suggests that the SNARC and related effects do not apply to this syntax-space effect if one just considers issues of magnitude such as word length and degree of saliency.

Of course, position in sentence is still an issue. The question remains as to whether or not the syntax-space effect results from the word order and left-to-right orthography of English. It is possible that readers (or perhaps language comprehenders in general) assign whatever actor they encounter first into the left side of space and the second actor to the right side of space. In other words, the concept of agency is not the driving factor of the specific lateral spatial bias we have observed. This issue will also be explored further in Experiments 6, 9, and 10.

CHAPTER 5

EXPERIMENT 4

Although the purpose of E3 was to establish that the spatial compatibility effect is not just a result of the serial position in which a word appears in a sentence, but rather that it is the special status of the subject and object (or perhaps agent and patient) that produces the effect, it is possible that the variable nature of the final word in the sentence is to blame for the lack of a final-word right-side bias in E3. For example, in E3 all of the final words were nouns, though not of a consistent type or necessarily an object localizable in mental model space (e.g., some were temporal nouns such as *month* and others were locations such as *festival*). Assuming that the syntax-space effect is at base a non-linguistic phenomenon which is then further attenuated by the grammatical status of the word (a combination of STEARC and MARC effects, perhaps), the spatial effects I have reported so far should also be present in mere lists of objects. Specifically, serial position of a symbol in a sequence of symbols will impact how that symbol is subsequently localized in space, and this interaction should be largely present on the left hand.

Such an effect has of course already been observed in rote lists such as numbers (Dehaene, Bossini, & Giraux, 1993), months and letters of the alphabet (Gevers, Reynvoet, & Fias, 2003), and even musical tempo (Prpic, Fumarola, de Tommaso, Baldassi, & Agostini, 2013) and pitch (Rusconi, Kwan, Giordano, Umilta, &

Butterworth, 2005). However, anecdotal reports from a large number of number-space synesthetes (Galton, 1883) suggest that the nature of the number-space interaction has its basis in standard printing methods of number charts and calendars. In addition, Dehaene observed a much less pronounced SNARC effect in Arabic participants who had experience with numerical systems that run both left-to-right and right-to-left (Dehaene, Bossini, & Giraux, 1993); Hevia, de Girelli, Addabbo, and Cassia (2014) found infants prefer smaller magnitudes on the left than the right; and Rugani et al. (2015) found a similar effect for domestic chicks (*Gallus gallus*). Van Dijck and Fias (2011) also reported a left-to-right bias for items stored in working memory, although they did not investigate the separate contributions of the hand and space in this effect.

In this experiment, then, participants were presented with a series of symbols (e.g., *square, circle, triangle*) in the center of the screen, with all of the timing parameters of presentation the same as in the first three experiments. Following each sequence, a shape appeared on either the left or right of the screen, and the participant had to judge whether or not that shape appeared in the sequence, the basic hypothesis being that if order of presentation is indeed connected to spatial localization, then shapes presented at the beginning of the sequence would be responded to faster when appearing on the left than on the right, and vice versa for shapes appearing near the end of the list.

Methods

Participants

Thirty-six participants (26 female, 10 male, *M* age = 20.6) took part in this study for extra credit towards a psychology class. All participants were right-handed, native speakers of English with normal or corrected-to-normal visual acuity (self-reported).

Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

For this experiment I generated a series of randomly ordered sequences of 3 unique shapes, from an inventory of 6 distinctive characters in Wingdings font (●, ■, ♦, ♥, ★, ▲). This resulted in 120 possible permutations. Lists were presented in a white font against a black screen, each sequence appearing one shape at a time in the center of the screen for 500 ms/shape. After the presentation of a sequence, a shape appeared on the left or right side of the screen. Half of the time this was a shape from the sequence just presented, and on the other half of the trials it was one of the three remaining possible symbols. In block A participants responded to a symbol that was present with a left button press (with the left hand) and a symbol that was absent with a right button press (with the right hand). In block B participants had the opposite button mapping. During each block, participants were presented with all 120 items. Button mapping order was counterbalanced across participants. Each block was preceded by a practice of 12 items. Participants could only proceed into the experimental block after achieving over 60% accuracy. A final addition to this experiment (a feature which was kept for all subsequent experiments) was that participants placed their head on a chinrest in order to center the computer monitor in their field of view and prevent variability in distance between the head and the monitor. The experimental design resulted in the following conditions of interest: Order (First, Second, Third), Side (Left, Right), and Hand (LHand, RHand) (see Figure 5.1).

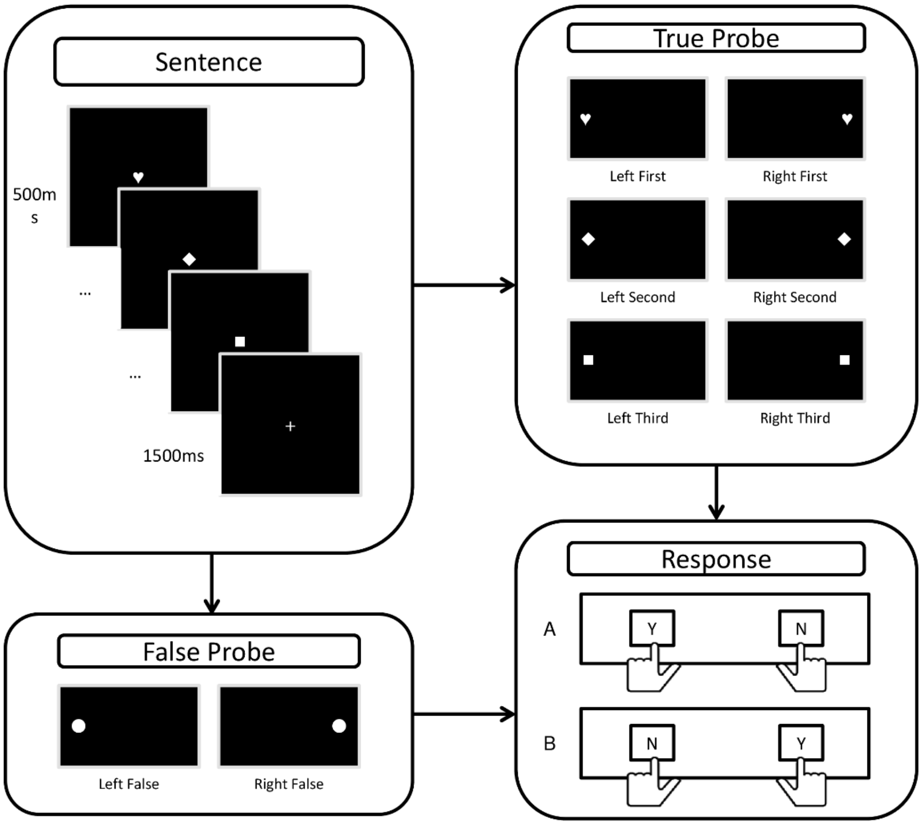


Figure 5.1. Schematic of sample trial from Experiment 4.

Results

As in previous experiment, before conducting data analyses incorrect probe responses from the dataset were removed from the dataset (11.18%). Next, I trimmed out extreme responses faster than 300 ms and slower than 3000 ms (0.66%). In all, then, 11.84% of responses were removed. Once again I looked at log-transformed RTs.

Data analyses followed the same procedure as before, using linear mixed-effects modeling with factors Side, Hand, and Order, as well as all possible interactions between the three factors. Items (lists of shapes) and participants were treated as random effects, with maximal random effect slope structure (Baayen, Davidson, and Bates, 2008). In contrast to previous experiments, it was found that removing the three-way interaction between Side, Hand, and Order did not account for a significant portion of model variance, $\chi^2(2) = 0.52$, $p = 0.77$. Removing the Order by Side coefficient did result in a statistically significant reduction in variance, $\chi^2(2) = 9.26$, $p = 0.01$ (see Figure 5.2). Since the factor Hand did not interact with Side or Order, I removed this factor from a bare model consisting only of the three main effects and found a significant change in model variance, $\chi^2(2) = 6.21$, $p = 0.05$, with a slight advantage for RHand responses (full model results reported in Table 5.1).

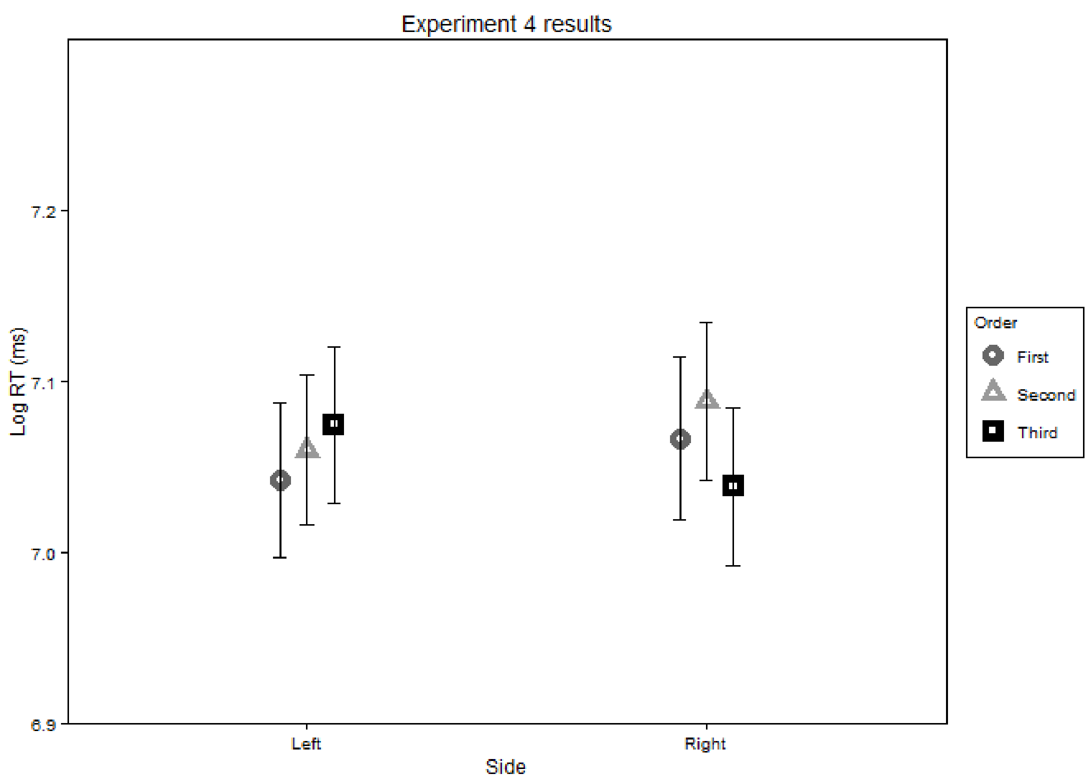


Figure 5.2. Graphical results of Experiment 4, showing the Side by Order interaction. Log-transformed RTs on the y-axis. Errors bars represent SE.

Table 5.1. Fixed effects for the max model in Experiment 4.

Coefficient Estimates - Baseline levels are First, Left Side, and Left Hand. *** indicates $p < 0.001$, ** $p < 0.01$, *$p < 0.05$, **.** borderline effects $p < 0.1$ and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	7.067	0.032	223.798	0.001***
β_1	Second	0.027	0.025	1.118	=0.264
β_2	Third	0.025	0.024	1.047	=0.295
β_3	Right	0.033	0.023	1.430	=0.158
β_4	RHand	-0.05	0.024	-2.082	=0.038
β_5	Second*Right	-0.006	0.033	-0.169	=0.866
β_6	Third*Right	-0.063	0.034	-1.861	=0.063 **.**
β_7	Second*RHand	-0.016	0.035	-0.444	=0.657
β_8	Third*RHand	0.048	0.034	0.142	=0.887
β_9	Right*RHand	-0.029	0.033	-0.859	=0.391
β_{10}	Second*Right*Rhand	0.033	0.048	0.705	=0.481
β_{11}	Third*Right*Rhand	0.011	0.048	0.229	=0.819

In order to explore the interaction between Side and Order I ran a series of pairwise comparisons using a Bonferroni adjustment. Two contrasts were significant: First objects on the Left were responded to faster than Second objects on the Right; and Third objects on the Right were responded to faster than Second objects on the Right (see Table 5.2 for all contrasts).

While the pairwise comparisons between First and Third shapes were not significant, I had a priori hypothesized there would be an advantage to responding to First Left shapes relative to Third Left, and vice versa for the Right side. This specific hypothesis was tested by calculating difference scores, subtracting response times to

Table 5.2. Experiment 4 pairwise comparisons for the two-way interaction between Side and Order.

Condition	Stat	LSecond	LThird	RFirst	RSecond	RThird
LFirst	*Est.*	-.012	-.028	-.014	-.049	.009
	SE	.017	.017	.017	.017	.017
	t	-.692	-1.64	-.812	-2.93	.548
	p	1	1	1	.05	1
LSecond	*Est.*		-.016	-.002	-.04	.021
	SE		.017	.017	.017	.017
	t		-.925	-.115	-2.19	1.22
	p		1	1	.43	1
LThird	*Est.*			.014	-.021	.037
	SE			.017	.017	.017
	t			.812	-1.26	2.15
	p			1	1	.48
RFirst	*Est.*				-.035	.023
	SE				.017	.017
	t				-2.08	1.34
	p				.56	1
RSecond	*Est.*					.058
	SE					.017
	t					3.42
	p					.01

Third shapes from First shapes on both the Left and Right sides, then comparing these difference scores. Indeed, there was a significant difference, $t(35) = 2.05$, $p = 0.05$, such that First – Third on the Left resulted in a negative score (i.e., a First shape response advantage, $M = -0.02$, $SE = 0.01$), while it was positive on the Right (i.e., a Third shape response advantage, $M = 0.01$, $SE = 0.01$).

Finally, in this experiment half of the trials consisted of responding to probe shapes that had not appeared in the previous sequence of shapes. In order to ascertain whether or not there were preexisting biases (or at least negative judgment biases, possibly related to the MARC effect) to responding to shapes on one side of the screen or the other with the left or right hand, I repeated the above-mentioned linear mixed effects modeling analyses on the False shapes with the fixed effects Hand, Side, and Hand x Side, with the same random effects as before, except with the variable Order removed from the random effect slope structure. Removing the interaction from this model did not lead to a significant change in variance, $\chi^2(1) = 0.02$, $p = 0.88$, nor did removing Hand, $\chi^2(1) = 0.1$, $p = 0.75$, nor Side, $\chi^2(1) = 2.58$, $p = 0.11$ (see Table 5.3 for maximum model details).

Table 5.3. Fixed effects for the False Probe max model in Experiment 4.

Coefficient Estimates - Baseline levels are Left Side and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p* <
β_0	(Intercept)	7.149	0.03	232.529	0.001***
β_1	RHand	0.002	0.016	0.125	=0.901
β_2	RSide	-0.02	0.016	-1.243	=0.214
β_3	RHand*RSide	0.004	0.023	0.153	=0.879

Discussion

The aim of this experiment was to test whether or not novel lists of objects would lead to the extemporaneous formation of left-to-right spatial mappings of the objects as ordered in the list and additionally to see if this effect interacts with the hand. Indeed, I did find such an effect, but this did not interact with response hand, as has so far been observed with language. Analysis of difference scores revealed the expected effect of first objects on the list responded to faster on the left and final objects being responded to faster on the right. In addition, pairwise comparisons revealed that first objects in the lists were responded to faster on the left than second objects on the right, while third objects on the right were responded to faster than second objects on the right. I did not have any a priori hypotheses about the spatial preference of second objects, but it is likely that primacy and recency effects may have contributed to the first and last objects generally being responded to quicker than the second objects. A clearer result would have been a neutral spatial positioning for the second object (similar to what van Dijck & Fias, 2011, found), but this could only have been tested with the introduction of a third level of the variable Probe Side, placing some probes along the midline. This will have to be tested in future experiments. In general, to my knowledge magnitude-space researchers have used a left-right spatial dichotomy, and not looked at graded position. In addition to these concerns, it is also possible that the type of objects used and the length of the lists (only three objects) limited the kinds of linear mappings participants would spontaneously form. Visuospatial cognition may be a useful mnemonic (e.g., Kosslyn, 1994; Luria, 1987), but mnemonics in general may be more readily used when the to-be-memorized items are significantly lengthy or complex enough to justify their need. However, this experiment is not testing whether or not participants use spatial mnemonics in memorizing lists, but rather whether or not they spontaneously associated order with space, as people have been shown to do with lists that have been memorized by rote (Dehaene, Bossini, & Giraux, 1993; Gevers, Reynvoet, & Fias, 2003). That I have shown this to be the case (perhaps somewhat counterintuitively) supports that the syntax-space effect reported in the first three experiments is not the same type of effect. First, the ordinal space effect from E4 did not interact with the hand, while in all previous experiments there were three-way interactions with hand and space. Second, if the findings from the current experiment involved the same mechanism as that which has led to the syntax-space effect, one would have expected to observe the final words of the sentences in E3 to show a right side bias. Thus, so far I conclude that the interactions between language, space, and hand are not merely effects of word order. However, there are problems comparing bare lists to sentences. For one thing, lists lack inherent structure, whereas sentences are structured. Nevertheless, the spatial bias of the structure in question is the ultimate question of these experiments and this dissertation generally. Subsequent experiments will explore this further.

CHAPTER 6

EXPERIMENT 5

All of the experiments so far have involved the presentation of visual stimuli. While the results of Experiments 1-4 suggest that the syntax-space effect so far observed is not merely a result of reading in a left-to-right orthography in an SVO language, this conclusion would be strengthened by providing evidence from the auditory modality. According to the orthographic explanation, the effect should disappear if sentences and probes are heard and not read. Thus, by presenting the sentences binaurally and then presenting probes dichotically, it can be tested directly whether this effect vanishes without the visual medium. My hypothesis is that the syntax-space effect is indeed modality-independent and will remain with aural presentation.

Methods

Participants

Sixty-two participants (40 female, 22 male, *M* age = 20.89) took part in this study for extra credit towards a psychology class. All participants were right-handed, native speakers of English. Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

The design of this study was essentially the same as what was used in E3 with several important exceptions. The main distinction is that all stimuli (sentences, probe words, and comprehension questions) were presented in the auditory modality. Items from E3 were slightly modified (modifications were made according to some of the issues described below in E6) and recorded using Audacity (n = 160; see Table A.4 in the Appendix for all items). Another important modification to this experiment is that probes only consisted of proper names (either the subject or object from the sentence or a new name not appearing in any other item). Furthermore, comprehension questions followed each item. Participants heard a sentence presented through headphones, and following the sentence an auditory probe was presented either to the left or right ear. Half of the probes were new names (False probes), one fourth were the subject of the just-read sentence, and the other fourth the object. Participants were instructed to press either the left or right button on a button box if the probe was or was not in the sentence they had just heard. In Block A, a left button press corresponded to *yes* and a right button press corresponded to *no*. In Block B the opposite button mapping was used. Button mapping block order was counterbalanced across participants. The items were divided into two lists (1 and 2), with one list being presented per block and order of presentation counterbalanced across participants. Yes/no responses to the comprehension questions followed the same button mapping as per the current block. Each block was preceded by a practice set of 10 items. Participants were not allowed to advance into the actual experimental block until they had achieved over 60% accuracy on the practice items (counting both probe and comprehension question responses). As in the previous experiments, the variables of interest were Word (Subject, Object), Side (LEar, REar), and Hand (LHand, RHand) (see Figure 6.1 for a schematic representation of a sample trial).

Imageability rating study[7]

Given that I am interested in how language interacts with space, it is possible that the effects observed so far are a result of explicit mental imagery of the sentences. In order to test for this possibility, each of the items used in this experiment (as well as all of the items used in subsequent experiments) were rated by 151 participants (35 male, 116 female) for imageability on a scale of 1 (very imageable) to 5 (not at all imageable). See Table B.1 in Appendix B for all ratings listed by verb. The mean rating for items was 2.11, $SE = 0.03$. In order to see how well these ratings corresponded with other norms, I correlated these ratings to the imageability and frequency ratings of the same items that were included in the MRC Psycholinguitic Database (Coltheart, 1981). Of the 160 items included in this experiment, 139 had frequency ratings and 66 had imageability ratings in the MRC Database. Frequency was not correlated with the imageability ratings collected here, $r(137) = -0.098$, $p = 0.25$, while imageability ratings were negatively correlated across sets, $r(64) = -0.5$, $p < 0.001$ (in my ratings lower scores indicate more imageable words, and in MRC higher scores are more imageable).

Results

As I did in previous experiments, before conducting data analyses I removed all incorrect probe responses from the dataset (2.12%), as well as incorrect responses to comprehension questions (3%). Next, I trimmed out extreme responses faster than 300ms and slower than 3000ms (0.89%). In all, 6.01% of responses were removed. No

[7] I present imageability ratings in E5, although I tested the effect of imageability on previous and subsequent experiments as well; however, imageability did not interact with the syntax-space effect elsewhere. Thus, for the sake of brevity, the details are included here only. Additionally, it is worth noting that running the E5 analyses without including the imageability variable did not result in any syntax-space effect.

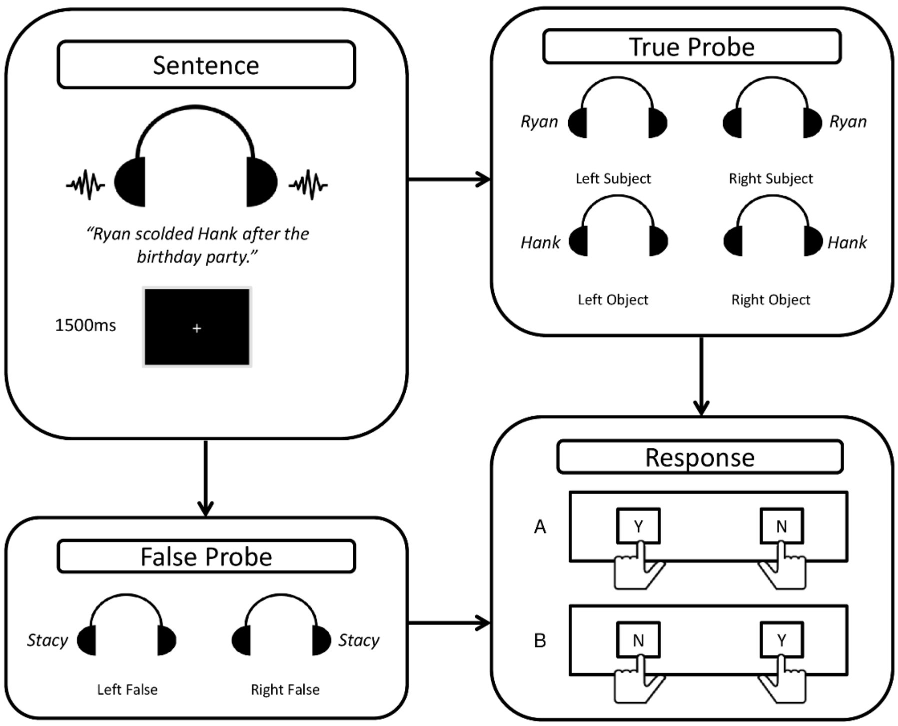


Figure 6.1. Schematic of sample trial from Experiment 5.

participants were removed from these data analyses. For the analyses reported below I looked at log-transformed RTs as per previous experiments.

Linear mixed-effects modeling was used again with within-subjects factors Ear (levels LEar and REar), Hand (levels LHand and RHand), Word (levels Subject and Object), and Item Imageability ratings as fixed effects, as well as all possible interactions between these four factors. Items and participants were treated as random effects with maximal random effects structure (Baayen, Davidson, and Bates, 2008). Removing the four-way interaction between Ear, Hand, Word and Imageability led to a statistically significant reduction in variance, $\chi^2(1) = 4.012$, $p = 0.05$. Full model results are reported in Table 6.1 and are displayed graphically in Figure 6.2.

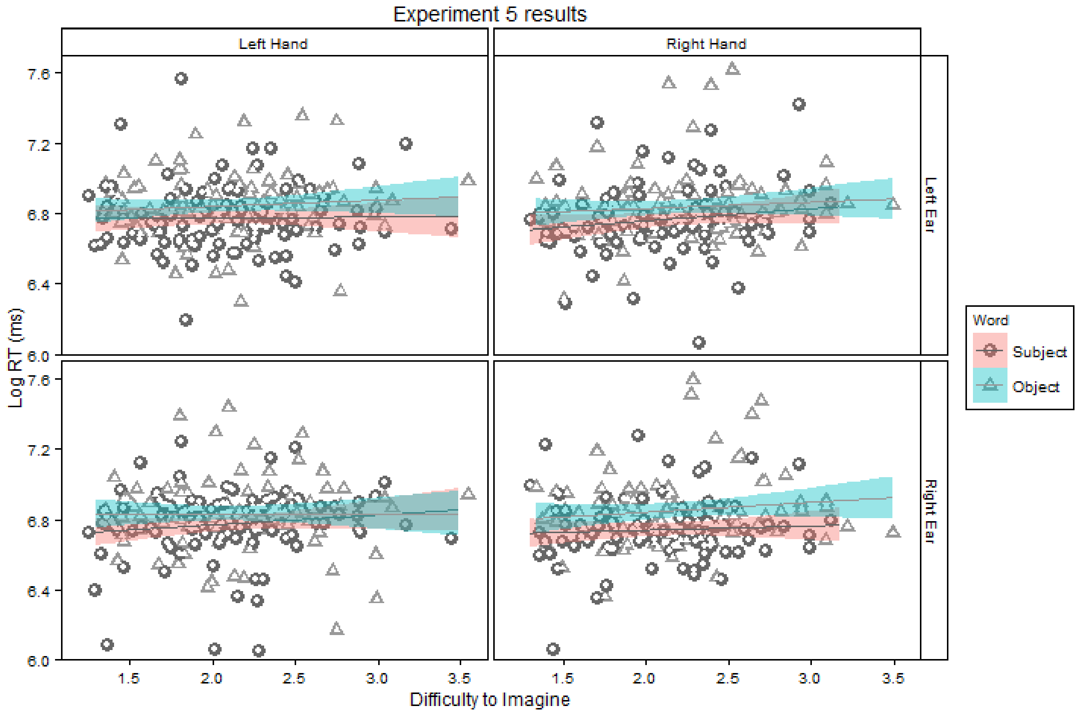


Figure 6.2. Graphical results of Experiment 5, showing the interaction between Word, Hand, Ear, and Imageability. Log-transformed RTs on the y-axis (note the expanded range relative to previously presented figures in order to include all data points), and Imageability ratings on the x-axis. Colored regions represent SE.

In order to better understand this interaction, I subset the data into Subject and Object datasets and repeated the model comparison technique with the variables Ear, Hand, and Imageability. For the Object data, the three-way interaction was not significant, $\chi^2(1) = 0.57$, $p = 0.45$, but there was a significant main effect of Hand, $\chi^2(1) =$

5.69, p = 0.02 (with faster responses on the RHand). None of the other effects were significant for the Object data. For the Subject dataset, the three-way interaction was significant, $\chi^2(1) = 4.04$, $p = 0.04$. To explore this interaction for the Subject dataset, I further subset the data down into Subject RHand and Subject LHand sets and repeated the above procedure. Within the Subject RHand set, the Ear x Imageability interaction was not significant, $\chi^2(1) = 0.88$, $p = 0.35$, but there were main effects of Ear, $\chi^2(1) = 3.81$, p = 0.05 (faster REar than LEar responses), and Imageability, $\chi^2(1) = 3.85$, $p = 0.05$ (which

Table 6.1. Fixed effects for the max model in Experiment 5.

Coefficient Estimates - Baseline levels are Left Ear, Object, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

Condition	*Est.*	*SE*	*t*	*p* <
(Intercept)	6.789	0.059	115.47	0.001***
Subject	-0.009	0.073	-0.118	=0.906
REar	0.064	0.076	0.849	=0.396
RHand	0.047	0.077	0.609	=0.542
Image	0.027	0.026	1.026	=0.305
Subject*REar	-0.172	0.103	-1.67	=0.095 **.**
Subject*RHand	-0.2	0.108	-1.842	=0.066 **.**
REar*RHand	-0.089	0.105	-0.849	=0.396
Subject*Image	-0.033	0.035	-0.939	=0.348
REar*Image	-0.025	0.036	-0.703	=0.482
RHand*Image	-0.037	0.036	-1.026	=0.305
Subject*REar*RHand	0.261	0.149	1.756	=0.079 **.**
Subject*REar*Image	0.083	0.049	1.714	=0.087 **.**
Subject*RHand*Image	0.094	0.05	1.873	=0.061 **.**
REar*RHand*Image	0.037	0.049	0.758	=0.448
Subject*REar*RHand*Image	-0.138	0.069	-2.003	=0.045 *

had a positive trend, $\beta = 0.04$, $SE = 0.02$). For the Subject LHand dataset, the Ear x Imageability interaction was significant, $\chi^2(1) = 4.36$, $p = 0.04$, characterized by no effect of Imageability on the LEar, $\chi^2(1) = 0.41$, $p = 0.52$, but a significantly positive trend on the REar, $\chi^2(1) = 3.89$, $p = 0.05$.These analyses confirm what can be seen in Figure 6.2: Object responses show no effects of Ear or Imageability, but responses are faster on the RHand; whereas for RHand Subject responses there are main effects of Ear and a positive trend for Imageability, but for LHand Subject there is an effect of Imageability on the R- but not the LEar.

As was done in E4, I reran the linear mixed-effects analyses with just the False probes included. The maximum model consisted of the fixed effects Hand, Ear, and Imageability, as well as all possible interactions between the three factors, with the same random effects as before (without Word). The three-way interaction was not significant, $\chi^2(1) = 0.25$, $p = 0.62$. The only significant interaction (though only marginally so) was Hand and Ear, $\chi2(1) = 3.68$, p = 0.06 (see Figure 6.3 and Table 6.2).

Discussion

The aim of this experiment was to test whether or not the syntax-space effect as I have shown previously would also be found in the auditory modality. The answer to this question is not a simple yes or no. There was a four-way interaction between probe word, ear, response hand, and the imageability of the item, a qualitatively different finding than what has been observed in previous studies, but which may nevertheless be reconciled with the overall hypothesis of this paper. In addition, there was a marginally significant interaction between response hand and ear for the absent probes, though post-hoc

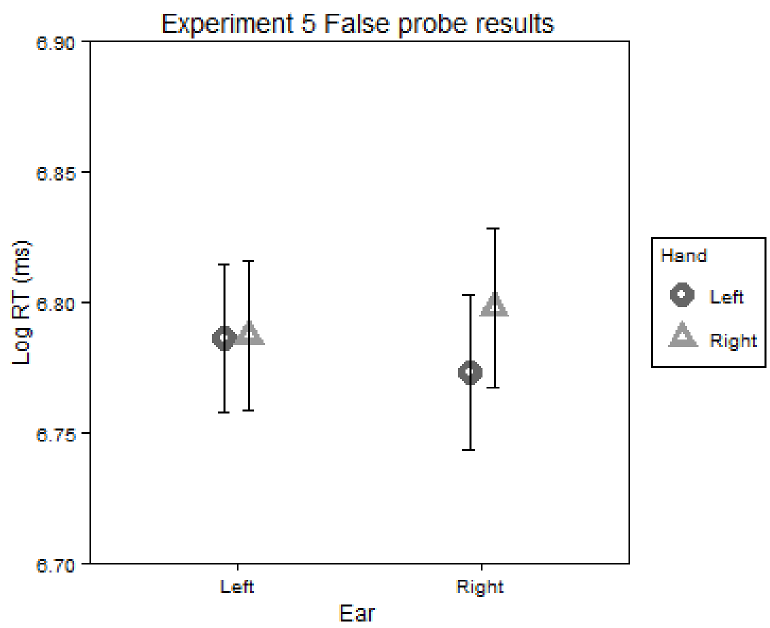


Figure 6.3. Graphical results of False probes from Experiment 5, showing the interaction between Ear and Hand. Log-transformed RTs on the y-axis. Bars represent SE. None of the post-hoc comparisons run on this interaction were significant, either with using a Bonferroni-adjusted p value or without (see Table 6.3).

Table 6.2. Fixed effects for the False Probe max model in Experiment 5.

Coefficient Estimates - Baseline levels are Left Ear and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.771	0.039	176.093	0.001***
β_1	REar	0.03	0.039	0.75	=0.453
β_2	RHand	0.014	0.043	0.328	=0.743
β_3	Image	0.008	0.016	0.508	=0.612
β_4	REar*RHand	-0.005	0.057	-0.084	=0.933
β_5	REar*Image	-0.02	0.019	-1.064	=0.287
β_6	RHand*Image	-0.007	0.02	-0.378	=0.706
β_7	REar*RHand*Image	0.013	0.027	0.5	=0.617

Table 6.3. Experiment 5 False Probe pairwise comparisons for the two-way interaction between Ear (Left Ear – LEar, Right Ear – REar) and Hand (Left Hand – LH, Right Hand – RH).

Condition	Stat	REarLH	LEarRh	REarRH
LEarLH	*Est.*	.0004	-.01	-.009
	SE	.006	.007	.009
	t	.066	-1.444	-1.045
	p	1	.894	1
REarLH	*Est.*		-.01	-.01
	SE		.009	.007
	t		-1.144	-1.444
	p		1	.894
LEarRH	*Est.*			.0004
	SE			.006
	t			.066
	p			1

comparisons revealed no significant effects. I will discuss the main interaction and its theoretical significance below.

Previous experiments did not find an interaction with the imageability of the experimental item. Thus, the main question to consider is why the imageability factor interacted in this experiment but not in the others. The clearest explanation seems to be that not using the visual medium in this experiment encouraged participants to engage in mental imagery (or alternatively was less taxing on the visuospatial sketch pad of working memory; Baddeley & Hitch, 1974). Effects of visuospatial imagery interference have been reported in the literature. Recall, for example, the Perky effect mentioned in the introduction: Perky (1910) first showed that when participants were asked to actively engage in mental imagery, this prevented them from detecting a target image flashed onto a screen. Notably, this effect occurs in both the visual and auditory domains (Segal &

Fusella, 1970) but does not seem to cause cross-modal interference. For example, auditory imagery does not lead to interference in detecting visual stimuli (Craver-Lemly & Reeves, 1992). It is possible, then, that the current paradigm encouraged participants to engage in mental imagery, whereas previously used visual paradigms discouraged this, as it would only add an unnecessary level of difficulty. While Perky effects are typically only observed when participants are explicitly told to imagine a percept (Reeves & Craver-Lemley, 2012), I cannot necessarily rule out the possibility that participants were consciously imagining the scenarios they listened to.

Related to this point, but somewhat distinct from it, is the possibility that not using the visual medium allowed participants to engage in mental imagery. This explanation would fit with the classic model of Baddeley and Hitch's (1974) working memory with its phonological loop, visuospatial sketchpad, and central executive components. Considering that this experiment was entirely auditory, the phonological loop would have been more engaged that the visuospatial sketchpad. In this case, mental imagery might have been employed in order to assist in comprehending the sentences and would not have interfered with performing the task. Interestingly, just as before the left hand showed a stronger spatial effect, but this time only for subjects. Moreover, the imageability factor only came into play on the right ear, which according to the main hypothesis of this dissertation is the dispreferred side for subjects. Regarding the left hand effect, again differences in hemispheric processing are implicated, and as for the side by imageability interaction, the implication is that more difficult to imagine sentences actually facilitate the syntax-space effect.

Nevertheless, the post-hoc nature of the imageability rating factor used in this experiment necessitates replication, perhaps using items at the extreme ends of the imageability scale. After reviewing the rest of the experiments detailed below, I will return to the E5 results in the General Discussion to judge how they fit in with the other results.

Chapter 7

Experiment 6

E1, E2, E3, and E5 found effects of a spatial bias for actors in transitive sentences, although the findings differed somewhat in nature. All four experiments found three-way interactions between hand, probe word, and probe side with stronger effects on the left hand, showing some cross-experiment concordance. The question remains, however, whether this is an effect of subject- and objecthood (i.e., order of mention) or agent- and patienthood (i.e., role in the transitive sentence). The most obvious way to test this is to see whether passivization of transitive sentences reverses the effect reported so far. If it does lead to a reversal, I can conclude that any relation between syntax and space is related to order of mention and not the underlying causal structure of the event. On the other hand, if there is no reversal, we can conclude that transitive sentences evoke a kind of spatial frame with placeholders for agents and patients. Thus, in E6 I add a further level of complexity to the design: sentence voice. In addition, rather than using a syntactic role judgment, gender judgment, or go/no-go task, this experiment adapts the present/absent task from E4 and E5.

Methods

Participants

Sixty-six participants (49 female, 17 male, *M* age = 20.6) took part in this study for extra credit towards a psychology class. All participants were right-handed, native speakers of English with normal or corrected-to-normal visual acuity (self-reported).

Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

In addition to testing the question of whether voice alters the syntax-space effect, I modified the methods of the previous experiments to resolve a few issues. The 160 items from E3 were used (see Table A.5 in the Appendix for a full list of items in both active and passive voices). Some items needed to be altered due to the fact that they sounded awkward when changed to the passive voice. Some names were also changed as well. As was done before, agent and patient names were equated for length (Agent M = 5.37, range: 3-9; Object M = 5.35, range: 3-10; $t(159) = 0.29$, $p = 0.77$). Gender of agents and patients remained balanced across items. I did not attempt to equate the length of active and passive sentences (i.e., no extra words were added to active sentences). Active sentences were an average of 6.44 words in length (range: 5-7), while passive sentences were an average of 8.44 words in length (range: 7-9). This difference in length, given the complications of the relation between magnitude and space, is potentially a problem for this task. I will address this further in the discussion.

The participants' task was to read the sentence (presented word-by-word in the center of the screen as before) and then respond to a probe word presented on the left or right side of the computer monitor that was either present in the sentence they had just read or was pulled from a list of unused names. Response were made on the left or right side of a Serial Response Box with either the left or right hand. As from E3 and E5 before, half of the trials included a False probe and the other half a Present probe. Following each probe was a yes/no comprehension question presented either in the active or passive voice. Voice of the comprehension question was crossed with voice of the item, encouraging participants to understand *who* was doing what to *whom* in the sentences. Yes/no button assignment corresponded to present/absent probe responses. After 80 items, button assignment switched. Order of button assignment was counterbalanced across subjects (see Figure 7.1 for a sample trial).

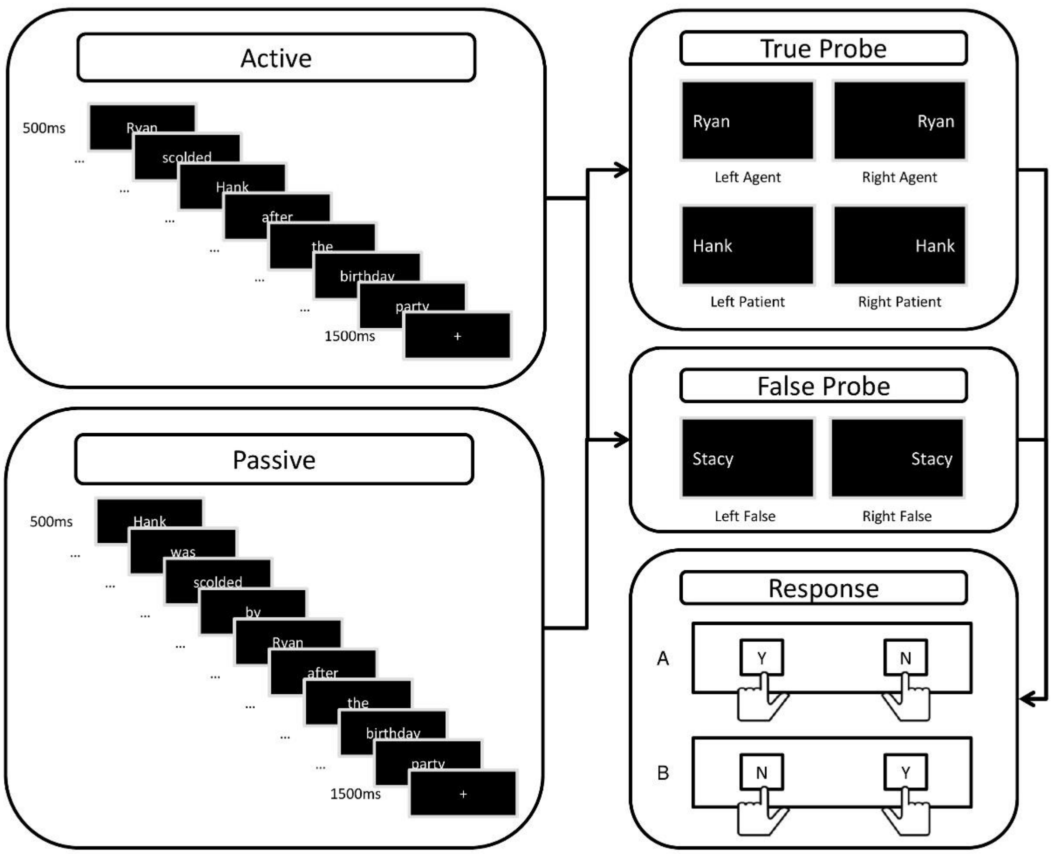


Figure 7.1. Schematic of a sample trial from Experiment 6.

Participants were given 10 practice items before each experimental block in order to grow accustomed to the button assignment. They were not allowed to advance into the actual experiment until they had achieved over 60% accuracy (counting both probe and comprehension question responses). This experimental design resulted in the following conditions of interest: stimulus presentation Side, response Hand, sentence Voice, and probe Word role[8].

Results

Following the same procedures from before, I removed all trials with incorrect probe responses (6.16%), those with incorrect responses to comprehension questions (15.12%), and those with extreme responses (0.42%), a total of 21.7% of trials. In addition, I removed five participants' data due to chance performance (M = 54%) on the comprehension questions. Note that the rather low accuracy on comprehension questions is likely due to the crossing between item voice and question voice, whereas in E3 and E5 items and questions were in the same voice.

Statistical analyses followed the same procedure as was followed in previous experiments, starting with the maximum model, and removing coefficient by coefficient in order to find the model of best fit (see Table 7.1 for the maximum model). Log-transformed RTs was the dependent variable, and Side, Hand, Voice, and Word were the independent variables. It was found that the four-way interaction was unnecessary, $\chi^2(1) = 1.6$, $p = 0.21$. Removing the three-way interaction between Side, Voice, and Word resulted in a significant reduction in variance, $\chi^2(1) = 3.9$, $p = 0.05$ (see Figure 7.2). Next, removing the Word, Hand, and Voice interaction also explained a significant amount of variance, $\chi^2(1) = 6.9$, $p = 0.009$ (see Figure 7.3). Removing other three-way interactions

[8] Note that in this experiment I refer to *agents* and *patients* as opposed to *subjects* and *objects*. Thus, an interaction between Word, Side, and Voice in this case would indicate a word order effect, while a Word and Side interaction would indicate a causal order effect.

did not result in any significant changes: removing the Side, Word, and Hand interaction, $\chi^2(1) = 2.61$, $p = 0.11$; removing the Side, Hand, and Voice interaction, $\chi^2(1) < 1$.

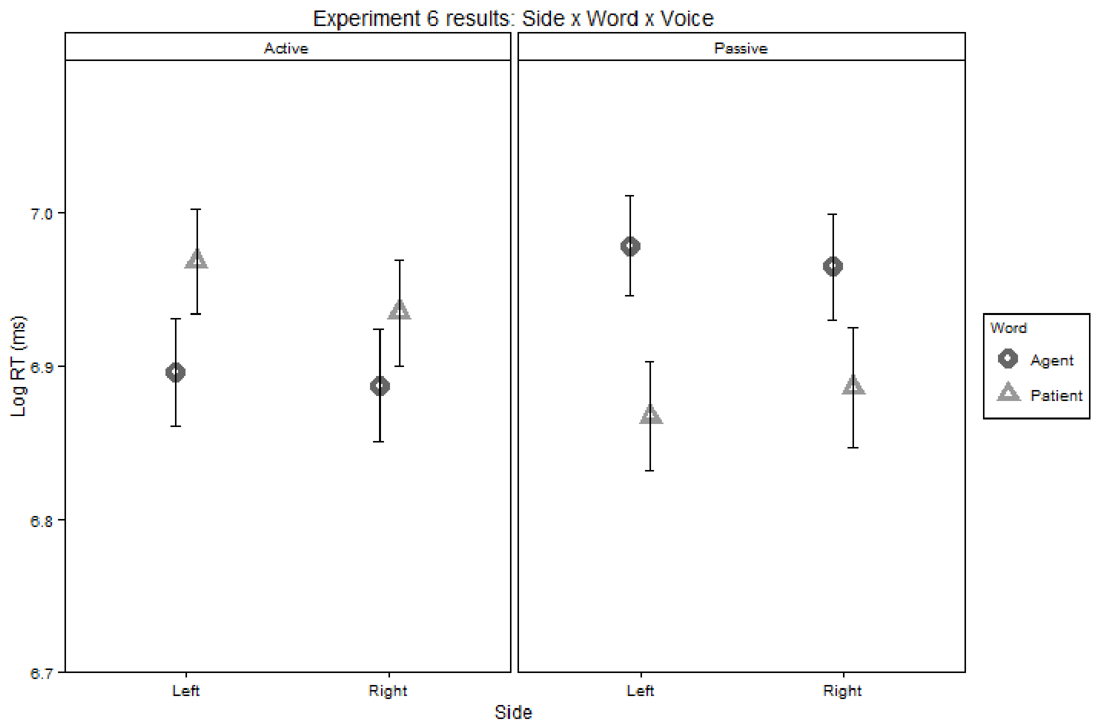


Figure 7.2. Graphical results of Experiment 6, showing the interaction between Side, Word, and Voice. Log-transformed RTs on the y-axis. Bars represent SE.

Next, I analyzed the interaction effects using pairwise comparisons, adjusting *p* values using the Bonferroni method, reporting only the theoretically significant results in the text and the rest of the comparisons in the respective tables. Regarding the interaction between Voice, Word, and Side, there was a significant advantage for Agent responses over Patient responses on the Left in the Active Voice, but this difference was not

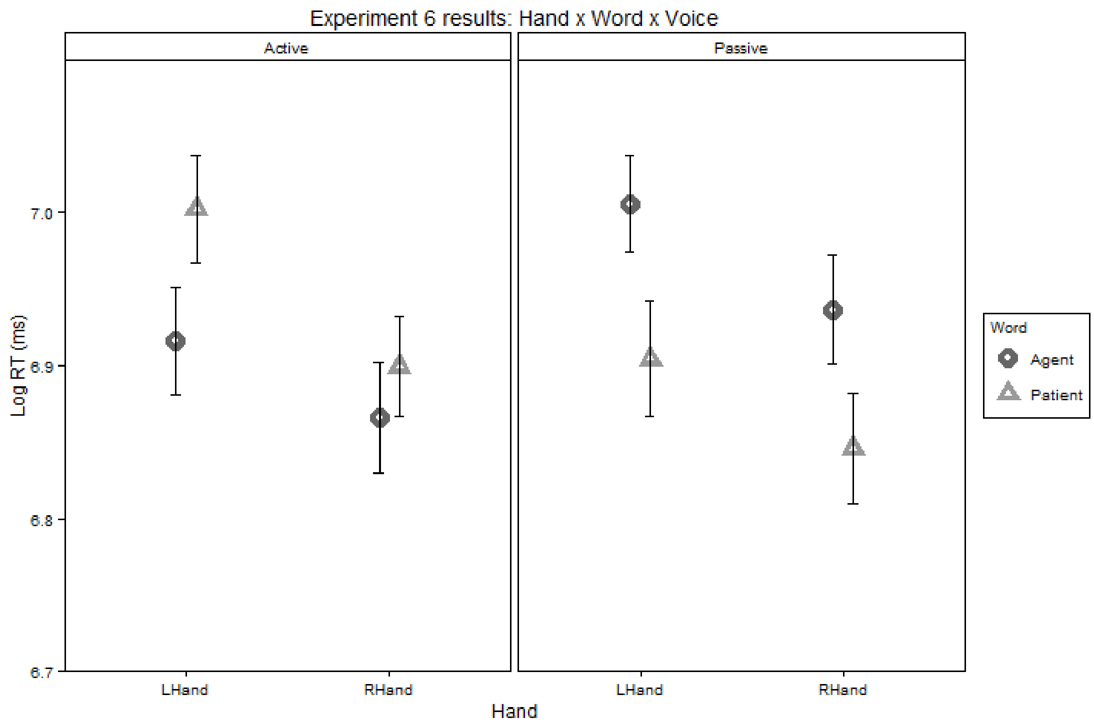


Figure 7.3. Graphical results of Experiment 6, showing the interaction between Side, Word, and Voice. Log-transformed RTs on the y-axis. Bars represent SE.

significant on the Right in the Active Voice. In the Passive Voice, Patient responses were faster than Agent responses on both the Left and Right. There was no difference between Active Agent and Passive Patient responses on the Left (see Table 7.2 for all contrasts and statistical details).

In addition to this set of pairwise comparisons, I tested whether or not Agents or Patients carried with them any lateral (Side) bias across differences in Voice. In order to do this, I first calculated the difference between Left and Right RTs for Active Patients (M = 0.014, SE = 0.007) and Passive Patients (M = -0.011, SE = 0.006), and found these to be significantly different, $t(60) = 2.26$, $p = 0.03$. I also did the same for RTs for Active

Table 7.1. Fixed effects for the max model in Experiment 6.

Coefficient Estimates - Baseline levels are Agent, Left Side, Left Hand, and Active Voice. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.916	0.024	283.081	0.001***
β_1	RightSide	0.031	0.02	1.543	=0.123
β_2	Patient	0.101	0.02	5.037	0.001***
β_3	RHand	-0.017	0.021	-.809	=0.419
β_4	Passive	0.111	0.02	5.509	0.001***
β_5	RightSide*Patient	-0.054	0.028	-1.898	=0.058 **.**
β_6	RightSide*RHand	-0.077	0.029	-2.673	=0.008**
β_7	Patient*RHand	-0.091	0.029	-3.173	=0.002**
β_8	RightSide*Passive	-0.039	0.029	-1.362	=0.173
β_9	Patient*Passive	-0.237	0.028	-8.383	0.001***
β_{10}	RHand*Passive	-0.039	0.029	-1.802	=0.072 **.**
β_{11}	RightSide*Patient*RHand	0.077	0.04	1.932	=0.053 **.**
β_{12}	RightSide*Patient*Passive	0.099	0.04	2.465	=0.014*
β_{13}	RightSide*RHand*Passive	0.05	0.04	1.234	=0.217
β_{14}	Patient*RHand*Passive	0.116	0.04	2.89	=0.004**
β_{15}	RightSide*Patient*RHand*Passive	-0.083	0.057	-1.460	=0.144

Agents (*M* < 0.0001, *SE* = 0.007) and Passive Agents (*M* = 0.0002, *SE* = 0.007), but found no significant difference, $t(60) = 0.03$, $p = 0.98$. Thus Agents were resilient to Side across Voice, while Patients were sensitive to Side as a function of Voice.

Turning to the other significant three-way interaction, Voice, Word, and Hand, this interaction was also explored using pairwise comparisons, again adjusting *p* values using the Bonferroni method and only reporting the theoretically significant contrasts in the text (see Table 7.3 for all contrasts). Focusing first on the Active Voice, there

Table 7.2. Experiment 6 pairwise comparisons for the three-way interaction between Side, Word, and Voice.

Condition	Stat	RAgA	LPatA	RPatA	LAgP	RAgP	LPatP	RPatP
LAgA	*Est.*	.004	-.056	-.033	-.081	-.062	.032	.014
	SE	.014	.014	.014	.014	.014	.014	.014
	t	.26	-4.02	-2.37	-5.73	-4.4	2.23	1.01
	p	1	.002	.5	<.001	<.001	.73	1
RAgA	*Est.*		-.06	-.037	-.085	-.066	.028	.011
	SE		.014	.014	.014	.014	.014	.014
	t		-4.28	-2.64	-5.99	-4.66	1.96	.75
	p		<.001	.24	<.001	<.001	1	1
LPatA	*Est.*			.023	-.025	-.006	.088	.071
	SE			.014	.014	.014	.014	.014
	t			1.65	-1.77	-.41	6.28	5.05
	p			1	1	1	<.001	<.001
RPatA	*Est.*				-.048	-.029	.065	.048
	SE				.014	.014	.014	.014
	t				-3.4	-2.05	4.63	3.4
	p				.02	1	<.001	.02
LAgP	*Est.*					.019	.113	.095
	SE					.014	.014	.014
	t					1.36	8	6.66
	p					1	<.001	<.001
RAgP	*Est.*						.094	.076
	SE						.014	.014
	t						6.66	5.45
	p						<.001	<.001
LPatP	*Est.*							-.017
	SE							.014
	t							-1.22
	p							1

Note: Abbreviation are as follows: Agent – Ag, Patient – Pat, R – Right Side, L – Left Side, Active – A, Passive – P.

was an advantage for responding to Agents over Patients on the LHand but no such advantage for the RHand. For the Passive Voice, there was an advantage for Patients over Agents on both the LHand and the RHand.

Table 7.3. Experiment 6 pairwise comparisons for the three-way interaction between Hand, Word, and Voice.

Condition	Stat	PAgLH	APatLH	PPatLH	AAgRH	PAgRH	APatRH	PPatRH
AAgLH	*Est.*	-.088	-.071	.02	.047	-.012	.025	.069
	SE	.014	.014	.014	.015	.015	.014	.015
	t	-6.21	-4.96	1.41	3.2	-.8	1.72	4.77
	p	<.001	<.001	1	.04	1	1	<.001
PAgLH	*Est.*		.017	.108	.135	.076	.112	.157
	SE		.014	.014	.015	.015	.014	.014
	t		1.18	7.57	9.21	5.24	7.9	10.92
	p		1	<.001	<.001	<.001	<.001	<.001
APatLH	*Est.*			.091	.118	.059	.096	.14
	SE			.014	.014	.014	.014	.014
	t			6.54	8.27	4.18	6.63	9.61
	p			<.001	<.001	<.001	<.001	<.001
PPatLH	*Est.*				.027	-.032	.004	.049
	SE				.014	.014	.015	.015
	t				1.86	-2.24	.29	3.32
	p				1	.7	1	.03
AAgRH	*Est.*					-.059	-.023	.022
	SE					.014	.014	.015
	t					-4.17	-1.58	1.5
	p					<.001	1	1
PAgRH	*Est.*						.036	.081
	SE						.014	.014
	t						2.56	5.63
	p						.3	<.001
APatRH	*Est.*							.044
	SE							.014
	t							3.16
	p							.05

Note: Abbreviations are as follows: Passive – P, Active – A, Patient – Pat, Agent – Ag, Left Hand – LH, Right Hand – RH.

Again for this interaction, I tested to see whether or not Agents or Patients carried with them any lateral (Hand) bias across differences in Voice by subtracting the scores of RHand from LHand and found similar findings as to what was found for the Side analysis. Responses to Active Patients (*M* = 0.036, *SE* = 0.007) and Passive Patients (*M* = 0.018, *SE* = 0.005) were significantly different, $t(60) = 2.27$, $p = 0.03$; however, there was no difference between Active Agents (*M* = 0.016, *SE* = 0.006) and Passive Agents (*M* = 0.031, *SE* = 0.008), $t(60) = 1.65$, $p = 0.11$.

Finally, as was done in E5 since this experiment involved responding to False probes, I analyzed these separately to test the possibility that responding to probes unassociated with any linguistic context will also interact with manuospatial processes. For this analysis the maximal model included the variables Hand, Side, and Voice, with participants and items as random factors with maximal random slope structure. As before I proceeded to remove interaction effects one by one, comparing the change in variance with the more complex model (see Table 7.4). The only significant effect was a main effect of Hand, with RHand responses slower than LHand, $\chi^2(1) = 8.79$, $p = 0.003$, likely

Table 7.4. Fixed effects for the max model of False probe responses in Experiment 6.

Coefficient Estimates - Baseline levels are Left Hand, Left Side, and Active Voice. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.87	0.028	244.684	0.001***
β_1	RightSide	-0.008	0.013	-0.647	=0.517
β_2	RHand	0.019	0.013	1.399	=0.162
β_3	Passive	0.007	0.013	0.556	=0.578
β_4	RightSide*RHand	-0.004	0.018	-0.204	=0.838
β_5	RightSide*Passive	-0.004	0.018	-0.234	=0.815
β_6	RHand*Passive	-0.004	0.018	-0.232	=0.817
β_7	RightSide*RHand*Passive	0.026	0.026	0.994	=0.32

indicating participants' preference to respond with their right hand to indicate correct responses and their left hand to indicate incorrect ones.

Discussion

In E6 I aimed to test the effect of sentence voice on the syntax-space effect that has so far been observed in these experiments. I also wondered how this effect would interact with the hand, namely response laterality. There were two different three-way interaction: Side x Word x Voice and Hand x Word x Voice.

First, the three-way interaction between stimulus side, sentence voice, and probe word may seem to be difficult to interpret, especially given all of the various contrasts reported above; however, a simple trend is apparent in Figure 7.2. Following active sentences, patients suffer a left-side response penalty, leading to a difference between agent and patient responses. However, no such penalty occurs on the right side. Agents do not appear to be preferred on either side. For the passive voice, patients are responded to just as quickly on the left as on the right, faster on both sides than the *by*-phrase agent on either side. Thus, it seems the spatial effect is present in active sentences and becomes reduced in passive sentences. Nevertheless, the difference scores analysis also revealed that agents have no lateral bias across voice, while there is a change in bias for patients across voice. Taking the two sets of analyses together it seems the interaction is driven by the change in patient lateral bias across voice, with a reduction of the effect in the passive. Importantly then, the results following passive sentences are not a mirror image of the results following the active sentences, showing that the causal structure of the sentences does play a role in these effects. Thus, the syntax-space effect is not due solely to the relative order of subject and object in the sentence.

Perhaps related to this three-way interaction between word, voice, and side is the other three-way interaction between response hand, voice, and word. Inspection of Figure 7.3 shows nearly the same effect that I just described, except now for *hands* as opposed to *space*. For the active voice there is an effect on the left hand, with agents faster than patients, but this effect disappears on the right hand. For the passive voice the difference in salience between agents and patients remains constant across hand. The difference scores analysis confirmed the findings of the pairwise comparisons. This further reinforces the role of the causal structure in these effects.

Finally and importantly, responding to the false probes in this experiment did not lead to any interactions between voice, hand, or space. An interesting finding was that there was a response advantage on the left hand as opposed to the right hand. A simple explanation for this is that participants prefer to use their right hand for correct responses and their left hand for incorrect ones (possibly because of the double connotation of *right* in English). This may be related to the MARC effect described in the Introduction.

Overall, while the effects of this experiment are strong and suggestive about a manuospatial representation of actors in a syntactic frame, given the differences I have reported across experiments, to what extent does this effect depend separately on hand and space? For example, in all the previous language experiments reported here, there has been a pronounced effect on the left hand. However in this experiment there was no left hand modulation of the syntax-space effect, but rather separate space and hand interactions. I explore this issue further in Experiments 7 and 8.

CHAPTER 8

EXPERIMENT 7

So far I have provided evidence for a syntax-space effect (E1 and E2), which is still present when response laterality is removed (E3), appears to be distinct from the SNARC effect (E4), and appears to have a stronger presence in active sentences (E6). While response laterality was removed in E3, responses were still made manually. Experiment 7 (E7), therefore, asks whether this effect remains when participants must make vocal responses using a similar design as was used in E6. My hypothesis is that indeed the syntax-space effect is intimately connected with the hand, and thus no effect will be present when manual responding is removed from the design.

Methods

Participants

Forty-one participants (29 female, 12 male, *M* age = 20.93) took part in this study for extra credit towards a psychology class. All participants were right-handed, native speakers of English with normal or corrected-to-normal visual acuity (self-reported). Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

The procedure was identical to that of E6 with two modifications. First, responses were made using a microphone connected to a Serial Response Box, used for measuring RT, as well as another microphone that recorded the actual responses. Microphones were placed side by side and angled towards the participant to maximize reception. Participants were instructed to say "yes" to probes that were in the previous sentence and "no" to probes that were not, and similarly to answers of the yes/no comprehension questions. The second change to the procedure was that there was no longer a second practice after the first experimental block. The reason for including this practice in E6 was to allow the participant to become acclimatized to the new button-response mapping, and as the present experiment used vocal responses, this was no longer necessary. Thus, in this experiment the factors of interest were Voice (Active, Passive), Word (Agent, Patient), and Side (Left, Right).

Results

Following the same procedures used previously, I removed all trials with incorrect probe responses (6.94%), those with incorrect responses to comprehension questions (13.05%) and those with extreme responses (8.78%), a total of 28.77% of trials.[9] In addition, I removed seven participants' data due to chance performance (M = 46%) on the comprehension questions.

Log-transformed RTs to probes were analyzed. Statistical analyses followed the same procedure as in previous experiments, starting with the maximum model, and removing coefficient by coefficient in order to find the model of best fit (see Table 8.1 for the maximum model). It was found that the three-way interaction between Voice, Word and Side was unnecessary, $\chi^2(1) = 0.02$, $p = 0.89$, so I proceeded to remove the two-way interaction coefficients from the model. The Side by Word interaction did not account for a significant amount of variance, $\chi^2(1) = 0.002$, $p = 0.96$; however, removing

[9] It is important to note that leaving in incorrect response trials did not alter the results reported below.

the Word by Voice interaction did lead to a significant change, $\chi^2(1) = 26.15$, $p < 0.001$ (see Figure 8.1). The Side and Voice interaction was also unnecessary, $\chi^2(1) = 1.32$, $p = 0.25$.

Table 8.1. Fixed effects for the max model in Experiment 7.

Coefficient Estimates - Baseline levels are Agent, Left Side, and Active Voice. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.92	0.028	244.684	0.001***
β_1	RightSide	-0.024	0.016	-1.448	=0.148
β_2	Patient	0.03	0.016	1.871	=0.061 **.**
β_3	Passive	0.029	0.016	1.81	=0.07 **.**
β_4	RightSide*Patient	0.003	0.023	0.132	=0.895
β_5	RightSide*Passive	0.02	0.023	0.889	=0.374
β_6	Patient*Passive	-0.08	0.023	-3.544	0.001***
β_7	RightSide*Patient*Passive	-0.005	0.032	0.14	=0.888

Next, I present post-hoc comparisons of the interaction between Word and Voice, using the appropriate Bonferroni method of p value adjustment. Active Agent responses were on average faster than responses to Passive Agents, $\beta = -0.039$, $SE = 0.011$, $t = -3.43$, $p = 0.004$, and Active Patients, $\beta = -0.031$, $SE = 0.011$, $t = -2.75$, $p = 0.036$, while Passive Patient responses were faster than responses to Passive Agents, $\beta = 0.051$, $SE = 0.011$, $t = 4.5$, $p < 0.001$, and Active Patients, $\beta = 0.043$, $SE = 0.011$, $t = 3.79$, $p < 0.001$ (see Table 8.2 for all contrasts).

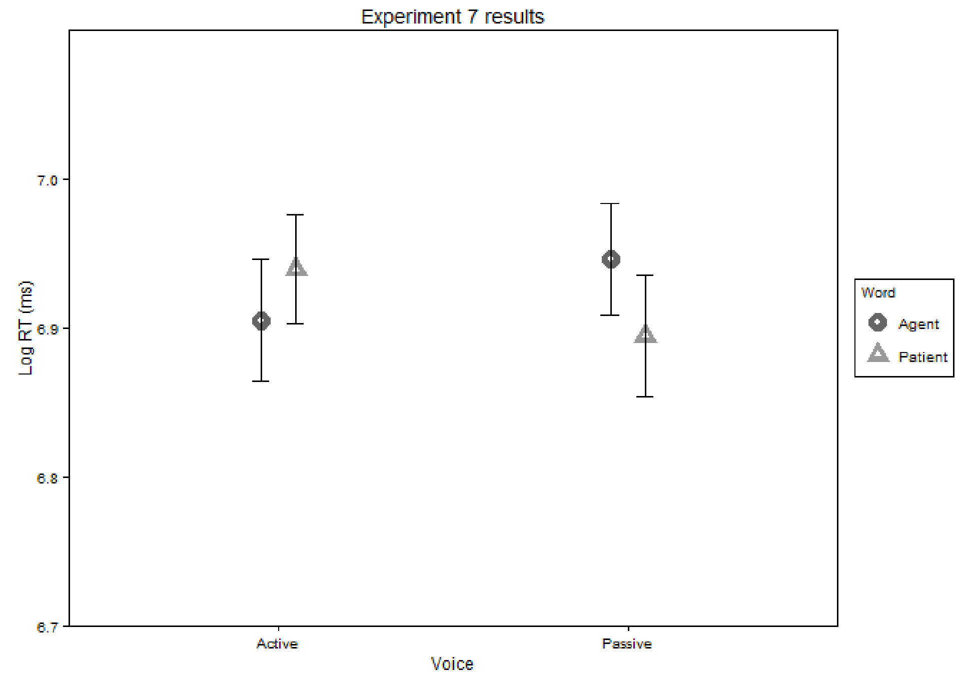


Figure 8.1. Graphical results of Experiment 7, showing the significant interaction between Voice and Word. Log-transformed RTs on the y-axis. Bars represent SE.

Table 8.2. Experiment 7 pairwise comparisons for the two-way interaction between Word and Voice.

Condition	Stat	PassAg	ActPat	PassPat
ActAg	*Est.*	-.039	-.031	.012
	SE	.011	.011	.012
	t	-3.43	-2.75	1.04
	p	.004	.036	1
PassAg	*Est.*		-.008	.051
	SE		.001	.011
	t		-.69	4.5
	p		1	<.001
ActPat	*Est.*			.043
	SE			.011
	t			3.79
	p			<.001

As was done in E4, E5, and E6, I analyzed the False probe responses only, using similar analyses as with the Present probe responses. The maximal model included the factors Side and Voice, and participants and items as random factors with maximal random slope structure. None of the effects were statistically significant (see Table 8.3 for the maximal model).

Table 8.3. Fixed effects for the False Probe max model in Experiment 7.

Coefficient Estimates - Baseline levels are Left Side and Active Voice. *** indicates $p < 0.001$, ** $p < 0.01$, *$p < 0.05$, **.** borderline effects $p < 0.1$ and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p* <
β_0	(Intercept)	6.955	0.028	248.032	0.001***
β_1	RightSide	-0.083	0.012	-0.72	=0.472
β_2	Passive	0.026	0.012	0.227	=0.82
β_3	RightSide*Passive	0.012	0.016	0.744	=0.457

Discussion

E7 failed to find a syntax-space effect. It did, however, find an interaction between probe word and sentence voice. This is somewhat similar to Ferreira's (2003) finding of greater difficulty in processing passives than actives, as well as the patient being more accessible following passive than active sentences. The lack of the syntax-space effect was expected and inspection of Table 8.1 shows that this was not a case of a lack of power, as there was not even a trend in the expected direction. Given that I failed to find a spatial interaction in this experiment, it seems likely that the syntax-space effect observed in the rest of the experiments is related to the specific manual motor effectors and their lateralization, especially given that the response hand typically interacted with various other effects. I explore this idea further in the next experiment.

CHAPTER 9

EXPERIMENT 8

In the previous experiments, there was either a word-hand effect (E6) or word-hand-side effects (E1, E2, E3, E5). These interactions could be explained in at least two ways: one possibility is that the results reflect an asymmetric representation of space developed as a result of right-handedness or orthographic direction of the native language; another possibility is that lateralized motor responses either directly or indirectly engage neural regions sensitive to spatial representations. The first of these explanations (the spatial hypothesis) would predict that responding towards the left side of space (which has so far shown a sensitivity to subjects vs. objects) would have similar results no matter which hand is responding (i.e., word, side, and hand would not interact with hand positioning). The second of these explanations (the manual hypothesis) would predict that the effect would remain on the left hand, no matter which side it is responding towards (i.e., a four-way interaction). Finally, it is possible that these results may be explained by a combination of these two hypotheses, in which case there would be a four-way interaction, but the results in the crossed position are not characterized by a null effect but rather an alteration of the syntax-space effect.

In addition to these main hypotheses two other parallel issues need to be addressed, which have only been referred to in passing before. First, brain lateralization and hand skill have frequently been implicated in these findings. So far, only right-handed participants (self-reported) have been tested, but within the right-handed population there is great variability in degree of handedness. Additionally, this has been shown to be related to language lateralization (Annett, 2002). Also, given the importance of cultural factors (i.e., exposure to left-to-right orthography) the amount of print material that participants have been exposed to may have had long-term developmental impact on attentional asymmetry (McConkie & Rayner, 1976). Both of these factors can be measured post-experimentally.

Methods

Participants

Sixty-seven participants (55 female, 12 male, *M* age = 20.45) took part in this study for extra credit towards a psychology class. All participants were right-handed, native speakers of English with normal or corrected-to-normal visual acuity (self-reported). Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

The 160 active versions of the sentences from E6 and E7 were used, presented word-by-word in the center of the computer monitor. Details of the design are nearly identical to those in E6, except that instead of the Voice variable, this experiment introduced the hand Position variable. Participants were instructed to press one button for *yes* (i.e., the probe was in the sentence) and one for *no* (i.e., it was not in the sentence) on either the left or right button on a button box. Button assignment was counterbalanced across blocks. In addition, participants were asked to position their hands in a normal or a crossed position across different blocks. This resulted in 4 separate experimental blocks to fully cross the hand position and response hand variables, with 40 items presented in each block (see Table 9.1). Block order was counterbalanced across participants, and each block began with a short practice (4 items).

Table 9.1. Crossing of response button and hand position blocks in Experiment 8.

Block	Left Button	Right Button	Hand Position
A	*yes*	*no*	normal
B	*yes*	*no*	crossed
C	*no*	*yes*	normal
D	*no*	*yes*	crossed

Following the response to a probe word, a comprehension question was presented to make sure participants were not simply memorizing names and were actually reading for comprehension. Comprehension questions required a button press with the same yes/no mapping as per the current block probe response mapping. Within these pairings half the questions required a *yes* and the others a *no* response. This design thus resulted in the following variables of interest: Hand Position (Normal vs. Crossed), Word (Subject vs. Object), Probe Side (Left vs. Right), and Hand (LHand vs. RHand) (see Figure 9.1).

Finally, at the end of the experiment participants filled out three forms: the first an Edinburgh Handedness Inventory (Oldfield, 1971), the second an Author Recognition Test (Acheson, Wells, & MacDonald, 2008; Stanovich & West, 1989), and third a reading habits survey (Acheson, Wells, & MacDonald; see Appendix B for all three surveys). Scores from these surveys were used in subsequent analyses to test for the possibility that handedness and print exposure interact with the syntax-space effect.

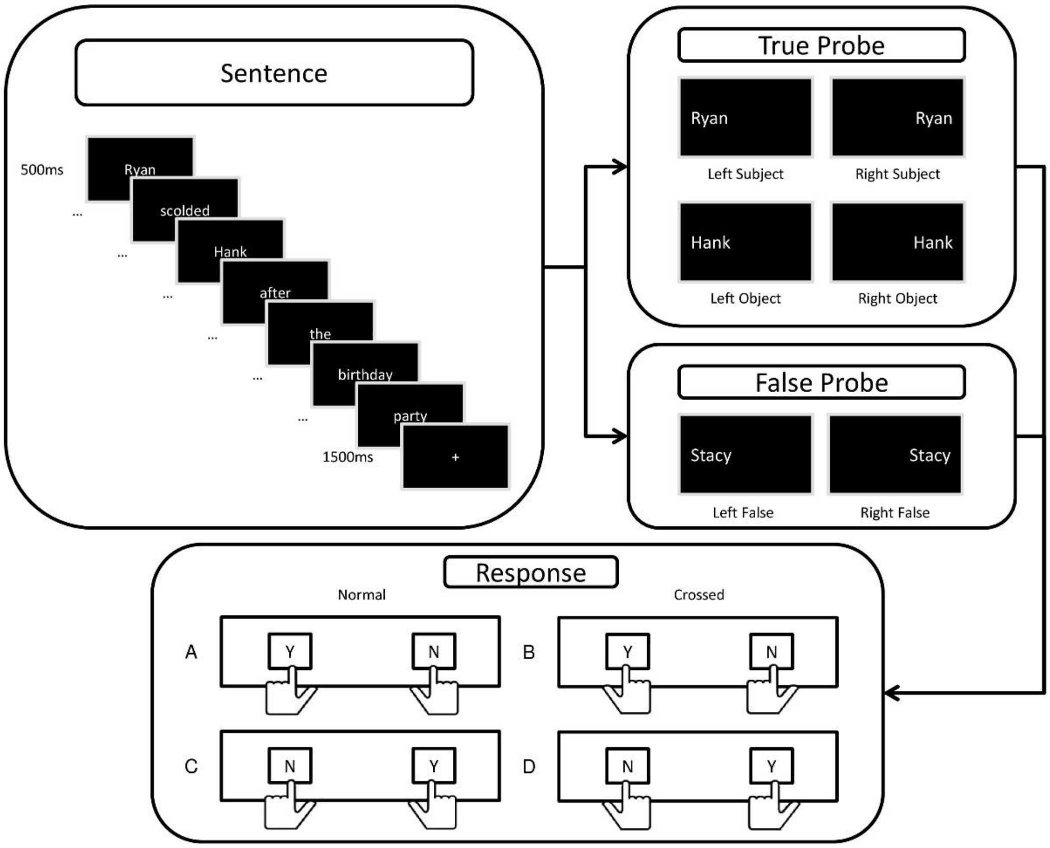


Figure 9.1. Schematic of sample trial from Experiment 8.

Results

Following the same procedures used previously, I removed all trials with incorrect probe responses (4.66%), incorrect comprehension questions (11.37%), and those with extreme responses (4.29%), a total of 8.95% of trials. In addition, we removed two participants' data due to low performance ($M < 60\%$) on the comprehension questions. Log-transformed RTs to probes were analyzed. Statistical analyses followed the same procedure as in previous experiments, starting with the maximum model, and removing coefficient by coefficient in order to find the model of best fit (see Table 9.2).

Table 9.2. Fixed effects for the max model in Experiment 8.

Coefficient Estimates - Baseline levels are Crossed Position, Object, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.998	0.025	284.679	0.001***
β_1	RSide	-0.053	0.017	-3.172	=0.002**
β_2	Subject	-0.044	0.017	-2.531	0.011*
β_3	Normal	-0.016	0.017	-0.896	=0.37
β_4	RHand	-0.033	0.017	-1.904	0.057 **.**
β_5	RSide*Subject	-0.008	0.024	-0.321	=0.748
β_6	RSide*Normal	0.022	0.024	0.905	=0.363
β_7	Subject*Normal	-0.101	0.025	-4.084	0.001***
β_8	RSide*RHand	0.056	0.024	2.337	0.02*
β_9	Subject*RHand	-0.026	0.025	-1.03	0.303
β_{10}	Normal*RHand	-0.045	0.025	-1.828	=0.068 **.**
β_{11}	RSide*Patient*RHand	0.08	0.03	2.369	=0.018*
β_{12}	RSide*Subject*RHand	0.006	0.03	0.189	=0.014*
β_{13}	RSide*Normal*RHand	-0.04	0.036	-1.2	=0.23
β_{14}	Subject*Normal*RHand	0.157	0.035	4.495	0.001***
β_{15}	RSide*Subject*Normal*RHand	-0.095	0.048	-1.986	=0.047*

It was found that the four-way interaction between Position, Word, Side, and Hand accounted for a significant portion of variance, $\chi^2(1) = 3.94$, $p = 0.05$ (see Figure 9.2), therefore I did not test any lower order effects and proceeded to analyze the four-way interaction in detail.

In order to get a better understanding of the four-way interaction, we divided the data into two sets—Crossed and Normal Position sets—isolating the levels of the Position variable and running separate linear mixed-effects models with the three

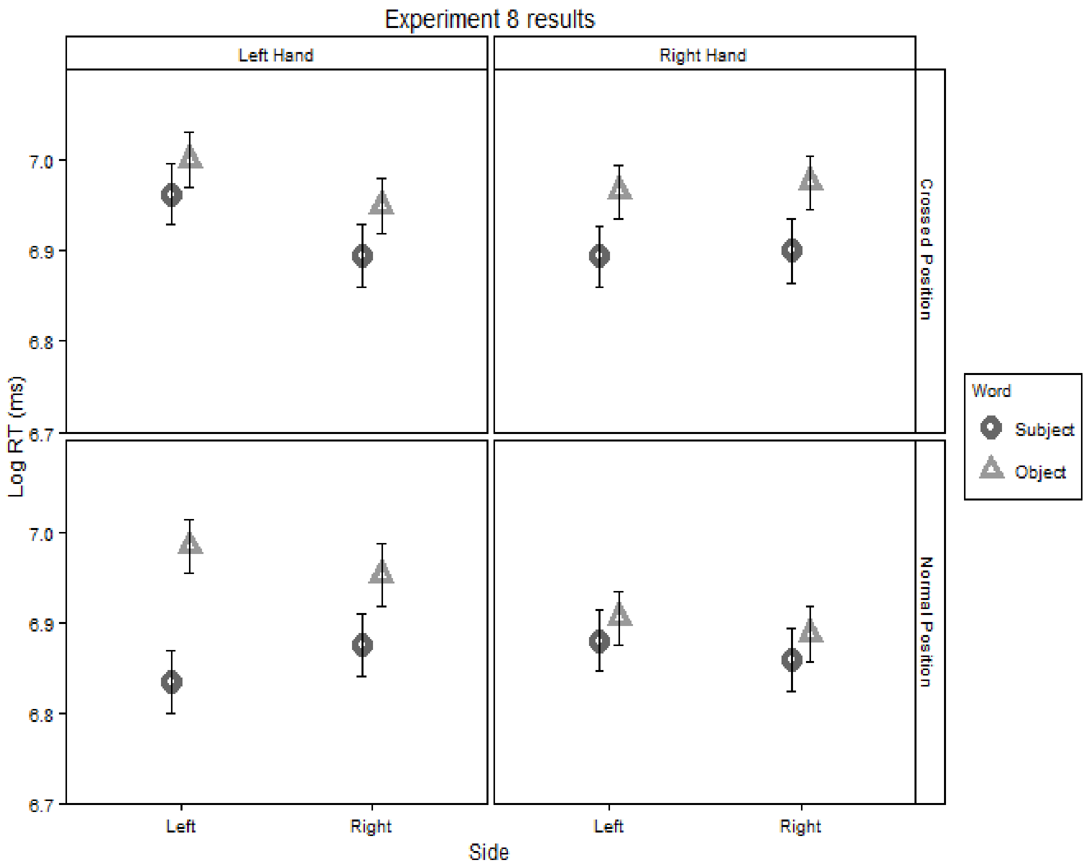


Figure 9.2. Graphical results of Experiment 8, showing the interaction between Position, Side, Hand, and Word. Log-transformed RTs on the y-axis. Bars represent SE.

remaining variables unchanged on these data. First we report the analyses of the Crossed Position set. The three-way interaction was not significant, $\chi^2(1) = 1.06$, $p = 0.3$. However, there was an interaction between Word and Hand, $\chi^2(1) = 5.64$, $p = 0.02$. In addition, there was a main effect of Side, $\chi^2(1) = 9.36$, $p = 0.002$, with Right Side responses faster than Left (see Table 9.3 for full model).

Bonferroni-adjusted pairwise comparisons of the Word by Hand interaction revealed that there was no difference between Subject responses on the L- and RHands.

Table 9.3. Fixed effects for the max Crossed Position model in Experiment 8.

Coefficient Estimates - Baseline levels are Object, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	7.017	0.024	298.817	0.001***
β_1	RSide	-0.049	0.014	-3.563	0.001***
β_2	Subject	-0.1	0.014	-7.284	0.001***
β_3	RHand	-0.059	0.014	-4.291	0.001***
β_4	RSide*Subject	0.023	0.019	1.193	=0.233
β_5	RSide*RHand	0.027	0.019	1.404	=0.161
β_6	Subject*RHand	0.056	0.019	2.905	=0.004***
β_7	RSide*Subject*RHand	-0.028	0.028	-1.028	=0.304

However, Object responses on the RHand were faster than on the LHand. See Table 9.4 for all contrasts. In addition, we calculated the difference between responding to Objects

Table 9.4. Experiment 8 pairwise comparisons for the Crossed Position two-way interaction between Word and Hand.

Condition	Stat	SubLH	ObjRH	SubRH
ObjLH	*Est.*	.078	.038	.084
	SE	.009	.009	.009
	t	8.523	4.204	9.813
	p	<.001	<.001	<.001
SubLH	*Est.*		-.04	.006
	SE		.009	.009
	t		-4.662	.625
	p		<.001	1
ObjRH	*Est.*			.046
	SE			.009
	t			4.985
	p			<.001

and Subjects on each hand and found that there was a *smaller* difference between responding to these words on the LHand (M = 0.042, SE = 0.001) than on the RHand (M = 0.072, SE = 0.013), t = 2.01, p = 0.05.

Regarding the Normal Position set, the three-way interaction between Side, Word, and Hand was significant, $\chi^2(1) = 3.73$, p = 0.05 (see Table 9.5 for full model). In general, this interaction was characterized by a lack of an effect on the RHand, with large differences between Subject and Object responses on the LHand (see Table 9.6).

Table 9.5. Fixed effects for the max Normal Position model in Experiment 8.

Coefficient Estimates - Baseline levels are Object, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.98	0.025	282.481	0.001***
β_1	RSide	-0.029	0.017	-1.687	=0.092 **.**
β_2	Subject	0.15	0.018	-8.458	0.001***
β_3	RHand	-0.075	0.017	-4.36	0.001***
β_4	RSide*Subject	0.078	0.024	3.187	=0.002**
β_5	RSide*RHand	0.003	0.024	0.142	=0.887
β_6	Subject*RHand	0.124	0.025	4.976	0.001***
β_7	RSide*Word*RHand	-0.066	0.034	-1.929	=0.054 **.**

More revealing still are the difference score analyses. I subtracted Subject from Object responses on each Side of each Hand, and compared Left to Right Side within the levels of Hand. For the LHand, the differences between Subject and Object responses were larger on the Left Side (M = 0.144, SE = 0.016), than the Right Side (M = 0.075, SE = 0.019), $t(65)$ = 3.04, p = 0.003, while on the RHand, there were no significant

Table 9.6. Experiment 8 pairwise comparisons for the Normal Position three-way interaction between Word (Subject – S, Object – O), Side (Left – Ls, Right – Rs), and Hand (Left – Lh, Right – Rh).

Condition	Stat	SLhLs	ORhLs	SRhLs	OLhRs	SLhRs	ORhRs	SRhRs
OLhLs	*Est.*	.15	.075	.101	.029	.101	.101	.115
	SE	.018	.017	.017	.017	.018	.018	.018
	t	8.421	4.339	5.777	1.684	5.699	5.762	6.498
	p	<.001	<.001	<.001	1	<.001	<.001	<.001
SLhLs	*Est.*		-.074	-.049	-.12	-.049	-.049	-.035
	SE		.017	.018	.018	.017	.018	.018
	t		-4.252	-2.753	-6.795	-2.805	-2.777	-1.942
	p		<.001	.168	<.001	.142	.155	1
ORhLs	*Est.*			.025	-.047	.025	.025	.039
	SE			.018	.017	.017	.017	.018
	t			1.436	-2.684	1.456	1.501	2.21
	p			1	.207	1	1	.766
SRhLs	*Est.*				-.072	.0001	.0003	.014
	SE				.017	.018	.018	.017
	t				-4.12	.007	.016	.804
	p				.001	1	1	1
OLhRs	*Est.*					.072	.072	.086
	SE					.018	.018	.018
	t					4.069	4.113	4.861
	p					.001	.001	<.001
SLhRs	*Est.*						.0002	.014
	SE						.017	.018
	t						.009	.775
	p						1	1
ORhRs	*Est.*							.014
	SE							.018
	t							.772
	p							1

differences between the Left (M = 0.023, SE = 0.018) and Right Sides (M = 0.016, SE = 0.018), $t(65) = 0.31$, $p = 0.76$, essentially a replication of the main finding from E1.

Next, I analyzed False probe responses separately to test the possibility that responding to probes unassociated with any linguistic context will also interact with manuospatial processes. For this analysis the maximal model included the variables Hand, Side, and Position, with participants and items as random factors with maximal random slope structure. As before I proceeded to remove interaction effects one by one, comparing the change in variance with the previous model (see Table 9.7) and found the three-way interaction to not be significant, $\chi^2(1) = 2.29$, $p = 0.13$. The Side by Hand interaction was not significant either, $\chi^2(1) = 0.001$, $p = 0.93$, nor were the other interactions: Hand by Position, $\chi^2(1) = 0.91$, $p = 0.34$; Position by Side, $\chi^2(1) = 0.16$, $p = 0.69$. The effect of Hand was not significant, $\chi^2(1) = 1.66$, $p = 0.2$; however, Position, $\chi^2(1) = 73.41$, $p < 0.001$, and Side, $\chi^2(1) = 4.11$, $p = 0.04$, both were, with faster responses in Normal Position and the Right Side respectively.

Table 9.7. Fixed effects for the False Probe max model in Experiment 8.

Coefficient Estimates - Baseline levels are Left Hand, Left Side, and Crossed Position.
*** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	6.933	0.023	300.705	0.001***
β_1	RSide	-0.001	0.012	-0.109	=0.913
β_2	Normal	-0.055	0.013	-4.354	0.001***
β_3	RHand	0.009	0.012	0.761	=0.447
β_4	RSide*Normal	-0.022	0.016	-1.352	=0.176
β_5	RSide*RHand	-0.017	0.016	-1.006	=0.315
β_6	Normal*RHand	-0.005	0.018	-0.261	=0.794
β_7	RSide*Normal*RHand	0.035	0.023	1.514	=0.13

Handedness

Next, I ran an a priori-determined analysis using the handedness scores obtained post-experimentally. I removed False Probe responses and Crossed Hands conditions from the data (essentially leaving a dataset similar to what was obtained in E1), then reran the linear mixed-effects model analyses, now with the variables Word, Side, response Hand, and Edinburgh handedness score (Edinburgh) and all potential interactions between these variables.[10] Removing the four-way interaction led to a significant reduction in variance, $\chi^2(1) = 5.32$, $p = 0.02$ (see Figure 9.3 and Table 9.8).

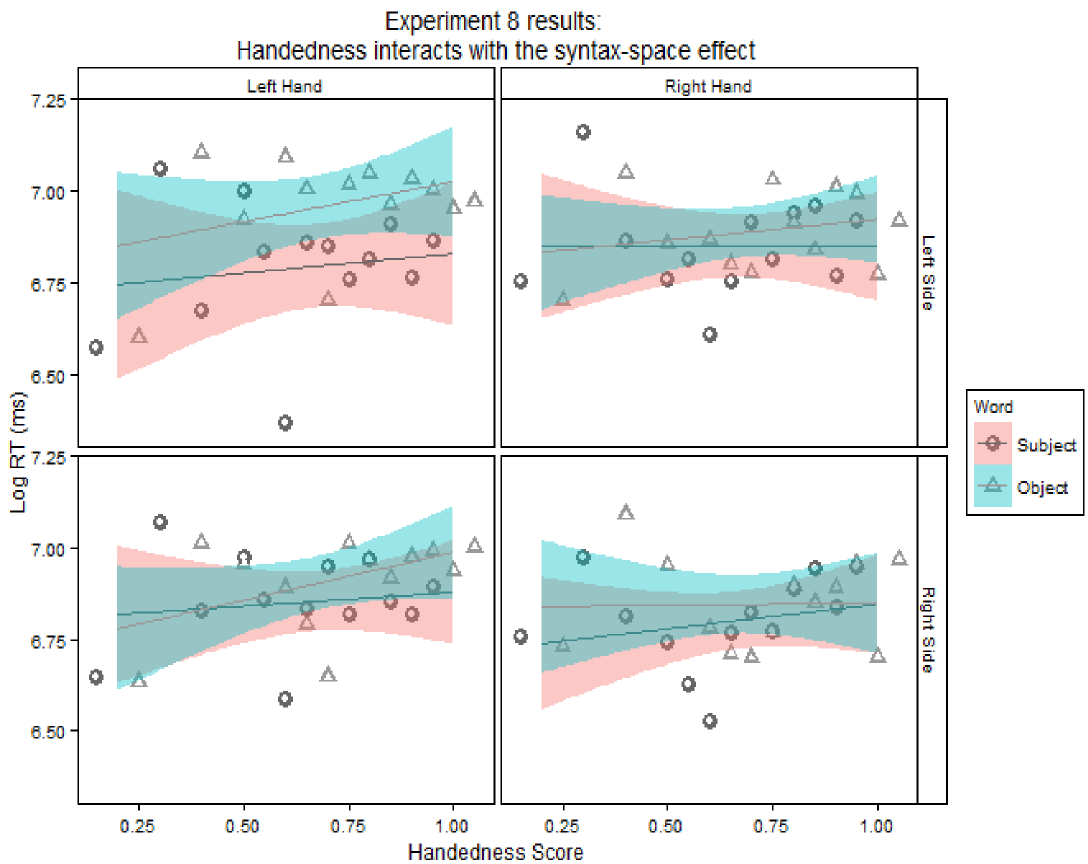


Figure 9.3. Experiment 8 results, showing the interaction between Handedness, Side, Hand, and Word. Log-transformed RTs on the y-axis. Edinburgh handedness scores on the x-axis (higher scores = more right-handed). Colored regions represent SE.

[10] Note that handedness scores were not included in the random slopes structure.

Table 9.8. Fixed effects for the max model in Experiment 8 including Handedness scores.

Coefficient Estimates - Baseline levels are Object, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p* <
β_0	(Intercept)	6.945	0.114	60.933	0.001***
β_1	Edinburgh	0.043	0.134	0.316	=0.753
β_2	RSide	-0.211	0.082	-2.562	=0.011*
β_3	Subject	-0.197	0.082	-2.389	=0.017*
β_4	RHand	-0.139	0.081	-1.716	=0.086 **.**
β_5	Edinburgh*RSide	0.217	0.097	2.234	=0.026*
β_6	Edinburgh*Subject	0.066	0.097	0.682	=0.495
β_7	Edinburgh*RHand	0.32	0.117	2.747	=0.006**
β_8	RSide*RHand	0.079	0.096	0.83	=0.407
β_9	Subject*RHand	0.13	0.115	1.132	=0.258
β_{10}	Subject*RHand	0.157	0.115	1.37	=0.171
β_{11}	Edinburgh*RSide*Subject	-0.3	0.138	-2.172	=0.03*
β_{12}	Edinburgh*RSide*RHand	-0.139	0.136	-1.023	=0.306
β_{13}	Edinburgh*Subject*RHand	-0.04	0.135	-0.296	=0.768
β_{14}	RSide*Subject*RHand	-0.459	0.164	-2.806	=0.005**
β_{15}	Edinburgh*RSide*Subject*RHand	0.446	0.193	2.308	=0.021*

To explore this four-way interaction, I divided the data along the factor Hand into two different datasets: LHand and RHand. Then I ran on each dataset separately linear mixed-effects models with the variables Side, Word, and Edinburgh, proceeding to remove variables one at a time as had been before. For the LHand dataset, the three-way interaction was significant, $\chi^2(1) = 4.36$, $p = 0.04$. Thus, I divided this dataset into Left and Right Sides, and tested for the presence of an interaction between Edinburgh and Word on each Side. On the Left Side set there was no interaction, $\chi^2(1) = 0.17$, $p = 0.68$, but there was a main effect of Word, $\chi^2(1) = 65.66$, $p < 0.001$ (Subject responses faster than Object responses). On the Right Side the interaction was significant, $\chi^2(1) = 6.25$, $p = 0.01$. This was characterized by an effect of Edinburgh for Object responses, $\chi^2(1) = 3.79$, $p = 0.05$, but not for Subject responses, $\chi^2(1) = 0.06$, $p = 0.82$.

For RHand, the three-way interaction was not significant, $\chi^2(1) = 1.11$, $p = 0.29$. Thus, I proceeded to remove lower-order interactions. This uncovered an interaction between Edinburgh and Side, $\chi^2(1) = 5.5$, $p = 0.02$, and also a main effect of Word, $\chi^2(1) = 3.89$, $p = 0.05$ (Subject responses faster than Object responses). The Edinburgh by Side interaction was characterized by no effect of Edinburgh on the Left Side, $\chi^2(1) = 1.3$, $p = 0.25$, and a positive slope on the Right Side, $\chi^2(1) = 4.64$, $p = 0.03$ (compare differences between the two rightward panels in Figure 9.3).

Print exposure

Again using the same Normal Position data set that was used to analyze the handedness data, I ran several analyses using the print exposure measures obtained post-experimentally.[11] The reading habits survey did not result in any interactions or main effects; however scores from the Author Recognition Test (Author) did, and for brevity I only present analyses run using that factor. First, there was not a significant four-way interaction between Author, Side, Hand, and Word, $\chi^2(1) = 0.001$, $p = 0.97$, nor a three-way interaction between Author, Side, and Word, $\chi^2(1) = 0.004$, $p = 0.95$. However, the interaction between Author, Side, and Hand did reach significance, $\chi^2(1) = 4.83$, $p = 0.03$ (see Figure 9.4 and Table 9.9). Author did not interact separately with the factor Word, $\chi^2(1) = 2.39$, $p = 0.12$.

[11] Note that I originally included both print exposure and handedness data in the analyses together, but these two factors did not interact with one another, so I present them separately for ease of understanding.

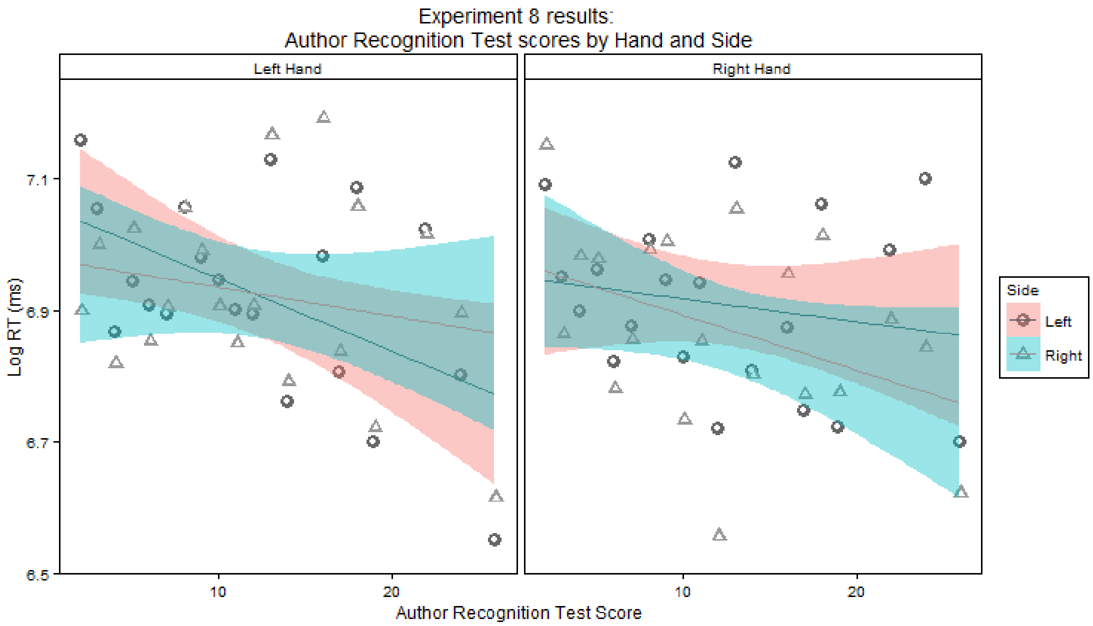


Figure 9.4. Experiment 8 results, showing the interaction between Author, Side and Hand. Log-transformed RTs on the y-axis. Author Recognition Test scores on the x-axis (higher scores = more correct responses). Colored regions represent SE.

Again, to explore this Author, Side, and Hand interaction, I broke up the data into LHand and RHand datasets and tested for Author x Side interactions within. For the LHand, the interaction was significant, $\chi^2(1) = 5.27$, $p = 0.02$. This interaction was characterized by a lack of an Author effect on the Right Side, $\chi^2(1) = 1.3$, $p = 0.25$, and a significant effect on the Left Side, $\chi^2(1) = 5.22$, $p = 0.02$.

For the RHand, the interaction was not significant, $\chi^2(1) = 0.98$, $p = 0.32$. In addition, the effect of Author did not reach significance, $\chi^2(1) = 2.35$, $p = 0.13$, but there was a main effect of Side, $\chi^2(1) = 4.14$, $p = 0.04$, with Right Side responses faster than Left Side responses.

Table 9.9. Fixed effects for the max model in Experiment 8 including Author Recognition Test scores.

Coefficient Estimates - Baseline levels are Object, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	7.073	0.052	137.514	0.001***
β_1	Author	-0.008	0.004	-2.034	=0.044*
β_2	RSide	-0.078	0.037	-2.124	=0.034*
β_3	Subject	-0.124	0.038	-3.296	0.001***
β_4	RHand	-0.129	0.037	-3.504	0.001***
β_5	Author*RSide	0.004	0.003	1.448	=0.148
β_6	Author*Subject	-0.002	0.003	-0.524	=0.6
β_7	RSide*Subject	0.069	0.053	1.305	=0.192
β_8	Author*RHand	0.005	0.003	1.705	=0.088 **.**
β_9	RSide*RHand	0.085	0.052	1.647	=0.1 **.**
β_{10}	Subject*RHand	0.141	0.053	2.673	=0.008**
β_{11}	Author *RSide*Subject	0.0003	0.004	0.073	=0.942
β_{12}	Author *RSide*RHand	-0.006	0.004	-1.541	=0.123
β_{13}	Author *Subject*RHand	-0.002	0.004	-0.379	=0.705
β_{14}	RSide*Subject*RHand	-0.087	0.074	-1.174	=0.241
β_{15}	Author *RSide*Subject*RHand	-0.0002	0.006	-0.037	=0.97

Discussion

The purpose of E8 was to get a better grasp on how the hand interacts with transitivity and space. In the introduction to this experiment, I proposed three different hypotheses: 1. The spatial hypothesis – interacting with a certain side of space drives the hand interactions, and thus crossing hands will lead to a reversal of the effect on the two hands; 2. The manual hypothesis – neural lateralization of motor effectors drives the effect, and thus crossing hands will not lead to any changes in how the hands interact with space and language. 3. The combination hypothesis – both interacting with a particular side of space and neural lateralization contribute to the effect, in which case the crossed hands position will be characterized by a reversal of the effect but much more reduced than in normal position.

I found a four-way interaction between Word, Hand, Side, and Position, which may support either the spatial or combination hypotheses, but certainly not the manual hypothesis. Considering first the responses to subjects and objects in the normal position, there was a replication of the effect observed in previous experiments (namely, E1, E2, E3 and to some extent E6). When the hands were crossed, however, this interaction disappeared, but there remained an interaction between probe word and response hand. In previous experiments, there was normally a sensitivity of the left hand to the probe word. For instance, in E1, E2, and E3 the syntax-space effect was stronger on the left hand. What is interesting in the E8 results is that in the crossed position the right hand now shows a sensitivity between subjects and objects, but not interacting with space. The fact that the right hand shows a greater difference between subject and object responses than the left hand indicates that the previously reported results are not simply due to differences in skill between the right and left hands. It seems that it is the interacting with the left side of space that is important. While one might object that it is still possible that interacting with the right side of space mitigates left hand performance difficulty and that interacting with the left side of space exaggerates these difficulties, to this objection I would cite the results for false probes in this experiment, which (according to this alternative explanation) should show a similar interaction but did not.

A question that remains is why the variable of space was no longer interacting in the crossed hands condition. This finding suggests something similar to what I have already stated but perhaps deserves further explication. Over the course of development, right-handedness results in a greater attention to and reactivity towards the right side of space (Buckingham & Carey, 2015). Indeed, pseudoneglect (i.e., a slight inattention to the left side of space present in healthy participants) is greater in dextrals than in sinistrals (Jewell & McCourt, 2000). While Rubichi and Nicoletti (2006) showed that the Simon effect shifts according to the position of the hands, there have not been over the course of these experiments strict Simon effects. Indeed, if anything, I have shown that the Simon effect does not apply to contextualized linguistic stimuli, but rather that a distinct effect applies (i.e., the syntax-space effect). Moreover, it seems that the mode of responding modulates the effect: lateralized responding exaggerates the influence of stimulus space and vocal responding eliminates it. In crossed-hands position, the response space effect (perhaps due to over-conscientiousness on the part of the participant, now very aware of the positioning of their hands) overrides the stimulus space, such that there is a difference between subjects and objects when responding towards the left but not the right, but the side of the stimulus no longer modulates the effect.

This experiment also showed that degree of handedness and measures of print exposure are important considerations. Regarding handedness, there was a four-way interaction between responses word, side, hand, and Edinburgh Inventory scores. This complex interaction can be summed as follows: an interaction between word, handedness, and side on the left hand, but not on the right, while on the right hand there was only an interaction between handedness and response side. The left hand effect can be further deconstructed into a main effect of word on the left hand/left side, and an interaction between handedness and word on the right side. Thus on the left hand/left side, the word effect remained despite handedness. Interestingly, on the left hand/right side the interaction between handedness and word indicated an advantage towards rightward object probes increasingly more for ambidextrous individuals. On the right hand, however, the syntax-space effect's interaction with handedness disappeared. In order not to confound the results of this experiment with handedness, I only recruited right handed participants as had been done previously. Clearly, these results suggest that the syntax-space effect is related to handedness (though not necessarily hand skill), and that the effect grows stronger in less strongly right-handed participants. A future experiment including strongly left-handed participants will need to be run to understand this better.

Finally, print exposure was also found to be important; however, it did not interact with the syntax-space effect (i.e., language, side, and hand), but rather with side and hand. While this might be interpreted as a caveat to the Simon effect, the fact that there have been no Simon effects detected in these experiments and that responding to contextualized word probes is qualitatively different than the types of tasks used in the Simon effect literature, this print exposure by side and hand interaction should probably be interpreted as an altogether different type of effect. On the right hand, right side responses were faster than left side responses, but on the left hand the left side advantage grew with better scores on the Author Recognition Test. This may suggest that participants who performed better on the test (and thus presumably read more) were better able to recover following leftward ballistic eye movements when stimulus and response dimensions were compatible.

To summarize the discussion: hand position matters for the syntax-space effect, indicating asymmetry of interactive space; additionally, handedness modulates this effect, mainly when the left hand responds to rightward stimuli, where more ambidextrous participants show stronger effects; print exposure does not interact with the syntax-space effect but may be an important area of investigation for general attentional effects.

CHAPTER 10

EXPERIMENT 9

All of the previous experiments have only used tasks where participants responded to word (or shape) probes, and while there clearly are interactions between language, space, and hand, it is less clear exactly what these interactions mean. Why, for example, is it the case that responses to patients are more sensitive to spatial effects and that in the active voice they are dispreffered on the left? Is it a result of lateral biases in word recognition, which are unrelated to mental imagery but rather are an interaction between the natural architecture of language, spatial, and manual systems? Results from E5 and lack of interactions with imageability ratings in other experiments suggest that mental imagery does not play a role when the visual medium is involved in the task.

One way to tease apart these problems would be to alter the paradigm to include images of transitive actions with the agent and patient positions manipulated. If responding to images following the reading of transitive sentences produces similar results as to what has already been observed, this would provide support for the possibility that the syntax-space effect is related to mental imagery. If on the other hand the results do not follow a similar pattern, it can be conclude that it is not imagery per se producing these results.

Several previous studies have looked at lateral biases in viewing or drawing scenes, and the results have been somewhat contradictory (described in detail in the

Introduction). My aim in this study is to use photographs of transitive actions (as opposed to drawings, which were used in Chatterjee, Southwood, and Basilico, 1999, and Maas and Russo, 2003) depicting a larger number of verbs than previously used, in order to investigate whether reading transitive sentences produces subsequent biases in scene processing. As I have done in previous experiments, I will also look at how syntax and agent position interact with the hand, if it all, something that has not been studied previously. I predict that there will be a similar pattern to what was found in previous experiments: in sum, the left hand will show a spatial effect (faster responses to images with agents on left and patients on right) and no effect on the right hand.

Methods

Participants

Forty-one participants (33 female, 8 male, *M* age = 20.35) took part in this study for extra credit towards a psychology class. All participants were right-handed, native speakers of English with normal or corrected-to-normal visual acuity (self-reported). Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

In this experiment participants read sentences and then respond to probes (images in this study). Sentences were presented one word at a time in the center of the screen at the same rate as was used in other experiments.

Half of the items were in the active voice and the other half in the passive. The content of the items for this experiment was dictated by the set of images from Hafri et al. (2012), who provided me with their stimuli. These authors were investigating the effect of the prototypicality of agents and patients on extracting the gist of a scene. A prototypical agent is one clearly engaged in an action, while a prototypical patient is not (perhaps being in a lax or uninvolved posture). Indeed, they found that the postures of agents and patients significantly impacted response times, such that non-prototypical patients led to increased RTs. In one of their experiments, they used stimuli depicting twins performing these actions. The twins were distinguished only by the colors of their shirts (red or blue). Importantly, they counterbalanced which twin was performing the action, as well as what side of the screen the agents and patients were on. I used 24 of the verbs from this study (although subsequently removed four of the verbs—*kiss, hug, feed, lift*—as the actors in the corresponding images were not separated enough in space, and were thus overlapping somewhat in the center of the image). A list of all the verbs used in this experiment is provided in Table A.6 in the Appendix.

In addition to manipulating the voice of the prime sentence, I also manipulated the parity of the image: matching or mismatching. In making their judgments, participants were indicating if the agent and patient indicated in the sentence were indeed fulfilling those respective roles in the image. Judgments were made with a left or right button press with the left or right hand). Hand position (i.e., crossed vs. normal) was not manipulated as it was in E8.

Finally, agent position (Left or Right) was manipulated by creating mirror images of all pictures. Participants encountered an equal number of Agent Left and Agent Right items.

The procedure consisted of two blocks, with 40 items per block and 80 items in all. Within each block individual verbs were presented twice, with matching and nonmatching versions of each item appearing. In the following block, the mirror image of the same items were presented. In addition, the voice of the item was changed across blocks. Thus, these were the factors of interest: Agent Side (Left, Right), Voice (Active, Passive), Hand (LHand, RHand) (see Figure 10.1). Each block began with four practice items.

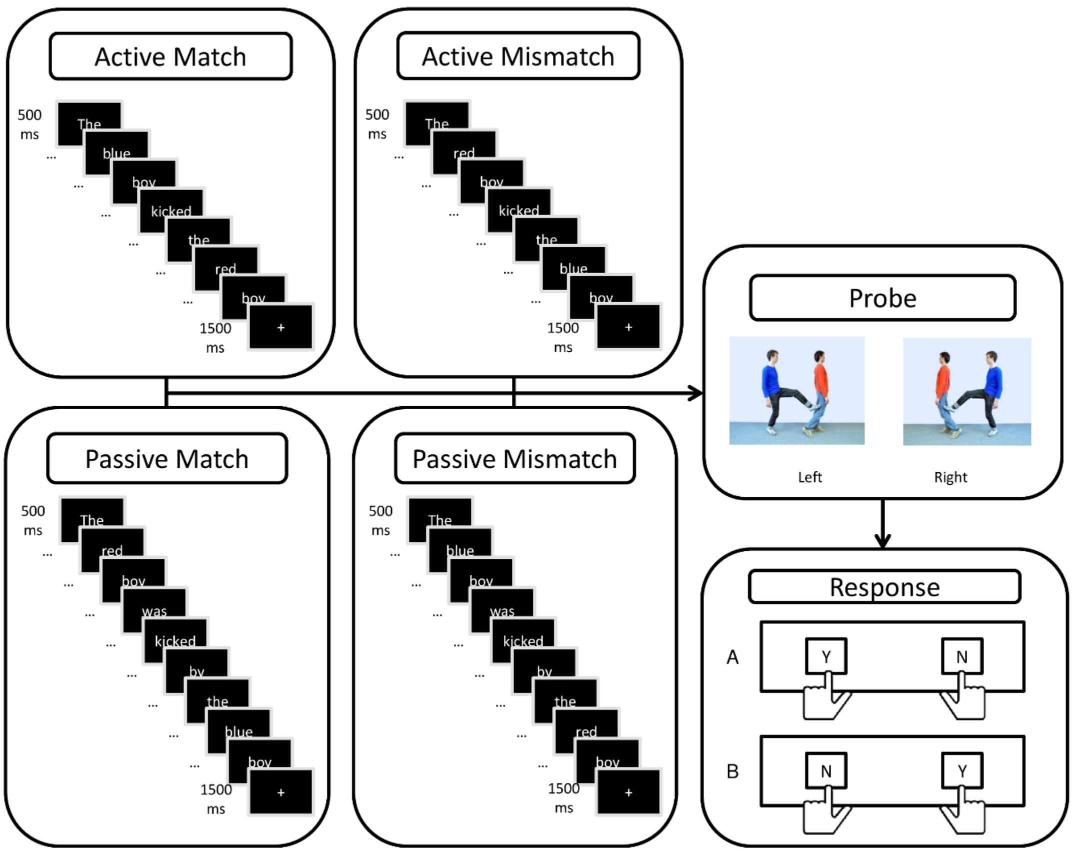


Figure 10.1. Schematic of sample trial from Experiment 9.

Results

Following the same procedures used previously, I removed all trials with incorrect probe responses (3.24%) and those with extreme responses (5.41%), a total of 8.65% of trials. Log-transformed RTs to probe images were analyzed. Statistical analyses followed the same procedure as in previous experiments, starting with the maximum model, and removing coefficient by coefficient in order to find the model of best fit (see Table 10.1 for the maximum model). It was found that the three-way interaction between Voice, Side, and Hand did not contribute a significant portion of variance to the model, $\chi^2(1) = 0.33$, $p = 0.56$. The interaction between Voice and Side was significant, $\chi^2(1) = 5$, $p = 0.03$. So was the interaction between Voice and Hand, $\chi^2(1) = 4.88$, $p = 0.03$. The interaction between Hand and Side was not significant, $\chi^2(1) = 0.04$, $p = 0.85$ (see Figure 10.2 for the two significant two-way interactions in side-by-side panels).

Table 10.1. Fixed effects for the max model in Experiment 9.

Coefficient Estimates - Baseline levels are Active, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p* <
β_0	(Intercept)	7.045	0.041	173.569	0.001***
β_1	RightSide	0.051	0.021	2.439	0.02*
β_2	Passive	0.079	0.02	3.85	0.001***
β_3	RHand	0.012	0.021	0.553	0.58
β_4	RightSide*Passive	-0.057	0.029	-1.994	0.046*
β_5	RightSide*RHand	-0.016	0.03	-0.543	0.587
β_6	Passive*RHand	-0.057	0.029	-1.974	0.048*
β_7	RightSide*Passive*RHand	0.024	0.041	0.577	=0.564

Next, I analyzed the interaction effects using pairwise comparisons. For each interaction I report adjusted *p* values using the Bonferroni method, reporting only the theoretically significant results in the text and the rest of the comparisons in the respective tables. Regarding the interaction between Voice and Side, there was a

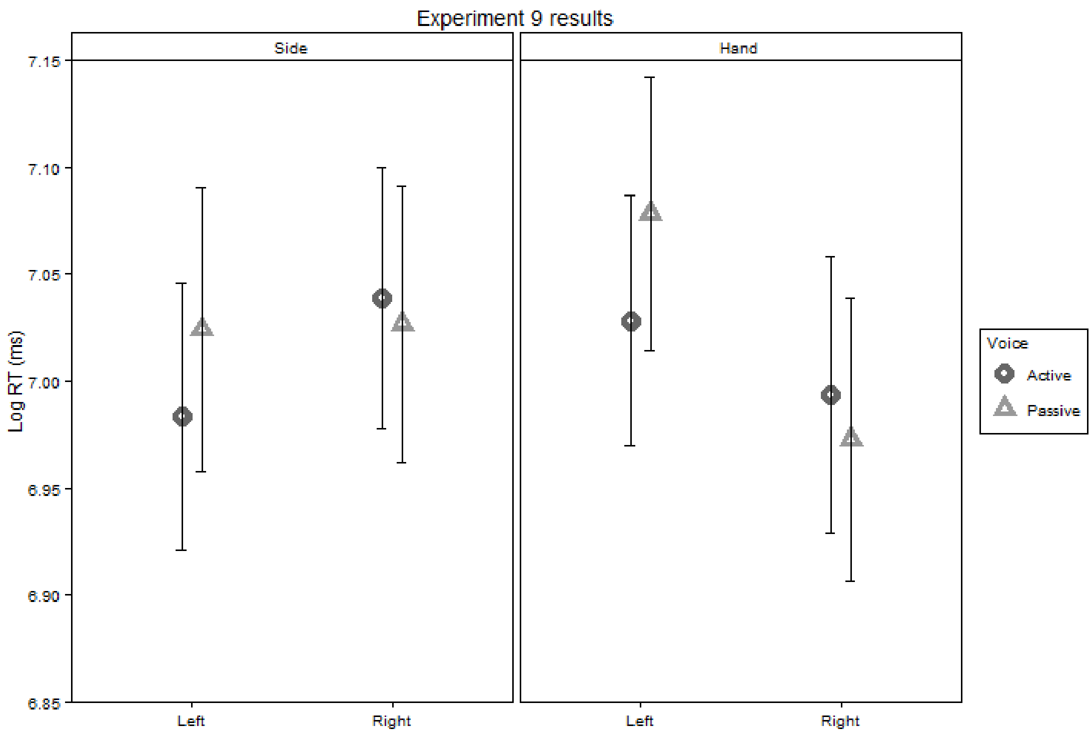


Figure 10.2. Graphical results of Experiment 9, showing: (left panel) the interaction between Side and Voice; and (right panel) the interaction between Voice and Hand. Log-transformed RTs on the y-axis. Errors bars represent SE.

significant advantage for Agent responses on the Left compared to the Right following a sentence in the Active Voice. In addition, Agent responses on the Left were responded to faster following an Active than a Passive sentence. The contrast between Agent responses on the Left or Right following Passive sentences was not significant (see Table 10.2 for all contrasts). Additionally, the difference scores between responding to Agent Left and Right images following an Active sentence (M = -0.024, SE = 0.01) was much larger than following a Passive sentence (M = 0.003, SE = 0.009), $t(40) = 2.04$, $p = 0.05$.

Table 10.2. Experiment 9 pairwise comparisons for the two-way interaction between Side and Voice.

Condition	Stat	RAct	LPass	RPass
LAct	*Est.*	-.055	-.051	-.045
	SE	.019	.019	.019
	t	-2.836	-2.642	-2.35
	p	.028	.05	.113
RAct	*Est.*		.004	.009
	SE		.019	.019
	t		.189	.489
	p		1	1
LPass	*Est.*			.006
	SE			.019
	t			.299
	p			1

Regarding the interaction between Voice and Hand, in general, the Passive Voice seemed to have a greater effect on manual responding than the Active Voice. For example, there was no difference between responding with the Left and Right Hands following the Active Voice. However, following the Passive Voice, RHand responses were faster than LHand responses (see Table 10.3 for all contrasts). Additionally, the difference scores between responding with the LHand vs. the RHand following an Active sentence ($M = 0.016$, $SE = 0.014$) was smaller than when following a Passive sentence ($M = 0.057$, $SE = 0.015$), $t(40) = 3.1$, $p = 0.004$.

As I did previously with False probes, I analyzed the responses to mismatching images only, using similar analyses as with the Present probe responses. The maximal model included the factors Side, Hand, and Voice, and participants and items as random factors with maximal random slope structure. None of the interaction effects were statistically significant: three-way interaction, $\chi^2(1) = 0.02$, $p = 0.89$, Side by Voice, $\chi^2(1)$

Table 10.3. Experiment 9 pairwise comparisons for the two-way interaction between Hand and Voice.

Condition	Stat	RHAct	LHPass	RHPass
LHAct	*Est.*	.041	-.06	.06
	SE	.02	.019	.019
	t	2.112	-3.11	3.069
	p	.209	.011	.013
RHAct	*Est.*		-.102	.018
	SE		.02	.019
	t		-5.179	.953
	p		<.001	1
LHPass	*Est.*			.12
	SE			.02
	t			6.141
	p			<.001

= 0.022, p = 0.88, Hand by Voice, $\chi^2(1)$ = 0.71, p = 0.4, Side by Hand, $\chi^2(1)$ = 0.38, p = 0.54. There was a main effect of Voice, $\chi^2(1)$ = 5.4, p = 0.02, with responses following Passive sentences slower than when following Active. There was no effect of Side, $\chi^2(1)$ = 2.59, p = 0.11, but there was a significant effect of Hand, $\chi^2(1)$ = 7.85, p = 0.005, with an advantage for LHand responses (see Table 10.4 for the maximal model).

Discussion

In this experiment I was interested in seeing whether or not the results observed in previous studies would also be found in a modified paradigm, which incorporated images instead of words. Indeed, there was an interaction between the voice of the prime sentence with both the side that the agent appeared on in the image and also the hand used to respond to that image. There was no three-way interaction. Thus, the results of this experiment seem very much in line with what observed in E6 in which voice and probe word type interacted with the probe side and response hand variables separately,

Table 10.4. Fixed effects for the mismatching images max model in Experiment 9.

Coefficient Estimates - Baseline levels are Active, Left Side, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	7.117	0.042	169.347	0.001***
β_1	RightSide	0.018	0.027	0.651	=0.515
β_2	Passive	0.047	0.027	1.746	=0.081 **.**
β_3	RHand	0.044	0.028	1.601	=0.11
β_4	RightSide*Passive	-0.008	0.038	-0.205	=0.838
β_5	RightSide*RHand	0.013	0.039	0.338	=0.735
β_6	Passive*RHand	-0.027	0.039	-0.697	=0.486
β_7	RightSide*Passive*RHand	0.008	0.055	0.141	=0.888

but in which there was no four-way interaction. Nevertheless, while these two experiments may superficially appear to report similar findings, the details of the interactions actually suggest different processes between the probe word and scene recognition tasks. In the rest of this discussion I will examine both of these interactions separately and explain their relation to previous findings.

First, regarding the interaction between agent position and sentence voice, recall that in E6 the Voice, Word, Side interaction was characterized by a penalty for responding to patients on the left side following an active sentence, while following a passive sentence RTs to patients were equally fast on the left and right and the same for agents. Difference scores showed that the behavior of patient responses changes with a left side penalty following active sentences and a left advantage following passive sentences. Agent side bias did not alter across voice. In E9, following active sentences, images with agents on the left and patients on the right were responded to faster than images with the opposite arrangement. Since agent and patient positions switched simultaneously, it is impossible to tell whether participants were in fact reacting to a patient-on-left penalty or a right-side-agent advantage (Experiment 10 deals with this issue). Note that the findings from Hafri et al. (2012) suggest that the entire image (and not just the agent or the patient) need to be assessed in order to decide what is happening in a scene. Furthermore, those authors used a fast presentation masking paradigm (30-70 ms of the image, followed by a mask), in order to rule out the possibility that the effect was simply one of left-to-right eye movements being faster and more efficient than right-to-left. Participants were able to extract the gist of the scenes within very little presentation time. Applying this knowledge to our findings, it seems that participants did not need to look back and forth at the actors in these images (indeed, most participants said the task was both easier and faster if they just responded based on gut feeling), but were nevertheless able to extract information from the scene faster when actors were in the preferred locations. Following the reading of a passive sentence, there was no longer a spatial effect. The reason for this is unclear. It is possible that both the results here and in E6 may reflect a working memory burden in processing passives, thus preventing access of the prototypical transitive spatial frame. The memory burden could possibly be a result of the causal structure mismatching the surface structure (Langacker, 2001). One way of testing this claim in the future is to introduce a dual-task paradigm. Presumably, if working memory load prevents these spatial effects from occurring, then the effect could also be eliminated in the active sentence condition when participants are dividing attention among the image judgment task and another (e.g., *n* back).

The Hand by Voice interaction is also similar to the E6 Hand by Word by Voice interaction. In that earlier experiment recall that in general right hand responses were faster than left hand ones. However, following an active sentence, response times to agent probes were no faster on the left or right hands, while following a passive sentence, there was a right hand advantage. Patient probes were responded to faster on the right hand following each type of sentence voice. The differences of left to right hand responses, however, showed that for agent responses there were no differences between the two voices, while for patients, left-right differences were greater following the active than the passive. Again, the picture emerging here is one of the sensitivity of the patient to hand and space. For E9 I found that, indeed, on the right hand there were no differences between voice, while on the left hand, responses following active sentences are faster than when following passives. This might be explained according to hemispheric processing differences, skill, or interacting with the left and right side of space. Given the findings reported in E8, the hemispheric processing differences (i.e., access to syntactic information may be faster on the right hand due to the overlap and adjacency of linguistic and praxic architecture in the LH) does make some contribution. Regarding the issue of manual skill, given the greater dexterity of the right hands in dextrals, any small processing differences between the active and passive voice would be negligible when responding with the right hand. However, when responding with the left hand, these processing differences may become aggrandized. An argument along similar lines would apply to differences in manual skill: there is a floor effect on the right hand, while on the left hand, processing differences between actives and passives reflect difficulty with the passive. However, I also showed in E8 that the performance of the hands changes based on whether they are in a crossed or normal position, with the left hand showing better performance than the right in the crossed position, while the reverse is the case in normal position. Given this finding, it seems most likely that the interaction in this experiment is also spatial in nature: the position of the hands in space. If participants are spontaneously generating transitive spatial frames, this might prime response space. A crossed hands experiment (or one where left and right hands respond along an orthogonal spatial axis) using this paradigm would be needed before reaching such a conclusion.

Chapter 11

Experiment 10

All the experiments run so far have looked at priming in one way or another. Thus, all that can really be concluded from them is that ongoing linguistic processes impact space and manual responding. However, one is left wondering whether or not these effects may also be long-term: are there developmental changes in manuospatial processing resulting from exposure to certain types of language? In this experiment I repeat E9 without the sentence prime, having participants respond only to images and decide which of the twins is performing the action. Given the fact that this is a non-linguistic task, I also compared how participants from different linguistic backgrounds (e.g., English vs. Arabic speakers) fare at this task.

Methods

Participants

Forty-eight participants (27 female, 21 male, *M* age = 21.81) took part in this study for extra credit towards a psychology class or cash. All participants were right-handed, 40 of which were native speakers of English, while 8 were native speakers of Arabic, both groups with normal or corrected-to-normal visual acuity (self-reported). Participants gave their informed consent to participate in this research under the guidelines of the USC IRB.

Procedure

The same stimuli used in E9 were used in this experiment with the exception that there were no prime sentences before the images were presented. Participants were asked to judge which twin (red or blue) in the image was performing an action and to press the left or right buttons of the button box accordingly using the left or right index fingers. Thus, in this experiment (unlike in E9) explicit attention was drawn to the agent of the image. Twin-to-button mapping was counterbalanced across blocks, and button mapping order was counterbalanced across participants. During each block an action was presented twice, the original picture and its mirror image, for a total of 40 trials per block and 4 trials total for the entire experimental session. Each block was preceded by 4 practice trials (see Figure 11.1 for a sample trial).

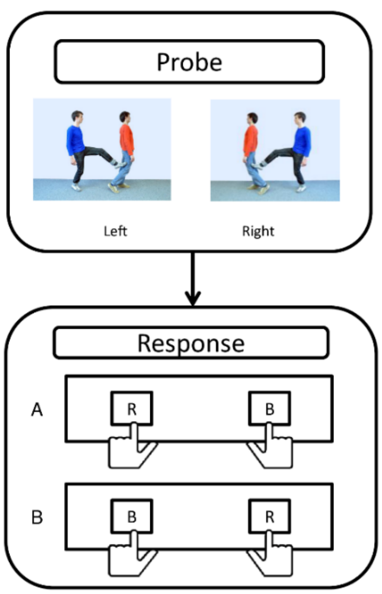


Figure 11.1. Schematic of sample trial from Experiment 10.

Results

Analyses for E10 followed the same procedure as previous experiments. Incorrect trials (5.51%) were removed, as were extreme responses (quicker than 300 ms and slower than 3000 ms; 1.77%). Thus, a total of 7.28% of the data were removed. Linear mixed-effects models found that the three-way interaction between Language, Hand, and Side was significant, $\chi^2(1) = 4.42$, $p = 0.04$ (see Table 11.1 for details of the maximum model and Figure 11.2).

Table 11.1. Fixed effects for the max model in Experiment 10.

Coefficient Estimates - Baseline levels are Arabic Language, Left Side Agent, and Left Hand. *** indicates p < 0.001, ** p < 0.01, *p < 0.05, **.** borderline effects p < 0.1 and > 0.05.

β	*Condition*	*Est.*	*SE*	*t*	*p <*
β_0	(Intercept)	7.019	0.088	80.043	0.001***
β_1	RSide	-0.02	0.036	-0.545	=0.585
β_2	English	-0.086	0.095	-0.905	=0.369
β_3	RHand	-0.031	0.036	-0.87	=0.384
β_4	RSide*English	0.096	0.039	2.451	=0.014*
β_5	RSide*RHand	0.021	0.0511	0.423	=0.672
β_6	English*RHand	0.078	0.039	1.979	=0.048*
β_7	RSide*English*RHand	-0.117	0.055	-2.103	=0.036*

Pairwise comparisons using a Bonferroni adjustment only found one significant contrast: English speakers responded faster to agents on the left than on the right when using their left hands (see Table 11.2 for all contrasts and statistical details).

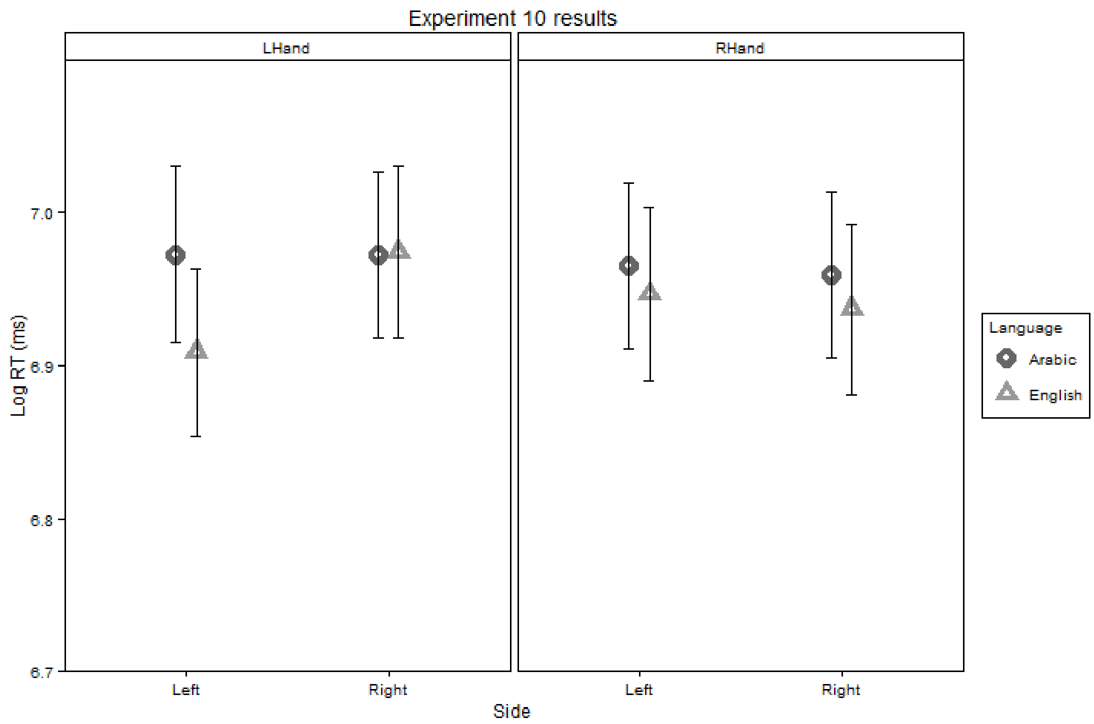


Figure 11.2. Graphical results of Experiment 10, showing the interaction between agent Side and Hand. Log-transformed RTs on the y-axis. Errors bars represent SE.

Difference score analyses looked at Left – Right response times on the LHand compared to on the RHand, looking at Language groups separately. For English speakers, there was a significant difference between the LHand (M = -0.03, SE = 0.007) and RHand (M = 0.007, SE = 0.006), $t(39) = 3.38$, $p = 0.002$. While for Arabic speakers the difference was not significant, LHand (M = 0.009, SE = 0.007), RHand (M = 0.002, SE = 0.014), $t(7) = 0.56$, $p = 0.6$.

Table 11.2. Experiment 10 pairwise comparisons for the three-way interaction between Language, Hand, and Side.

Condition	Stat	RsALh	LsARh	RsARh	LsELh	RsELh	LsERh	RsERh
LsALh	*Est.*	.02	.031	.029	.086	.009	.039	.058
	SE	.036	.036	.036	.096	.096	.096	.096
	t	.545	.869	.823	.889	.095	.408	.6
	p	1	1	1	1	1	1	1
RsALh	*Est.*		.012	.01	.066	-.01	.02	.038
	SE		.036	.036	.097	.097	.097	.097
	t		.322	.272	.686	-.108	.205	.397
	p		1	1	1	1	1	1
LsARh	*Est.*			-.002	.055	-.022	.008	.027
	SE			.036	.097	.097	.097	.097
	t			-.052	.565	-.228	.085	.276
	p			1	1	1	1	1
RsARh	*Est.*				.056	-.02	.01	.029
	SE				.096	.096	.096	.096
	t				.585	-.209	.104	.296
	p				1	1	1	1
LsELh	*Est.*					-.077	-.046	-.028
	SE					.016	.016	.016
	t					-4.811	-2.92	-1.768
	p					<.001	.099	1
RsELh	*Est.*						.03	.049
	SE						.016	.016
	t						1.893	3.074
	p						1	.06
LsERh	*Est.*							.019
	SE							.016
	t							1.17
	p							1

Note: Abbreviations are as follows: Arabic – A, English – E, Left Side – Ls, Right Side – Rs, Left Hand – Lh, Right Hand – Rh.

Discussion

Results of E10 show that when online linguistic processing is removed from the task, there remains a spatial bias which is modulated by the hand. Moreover, native language drives the effect. Specifically, English participants show a left-side-agent/left-hand effect, while Arabic participants show no effect. The fact that in this experiment, participants were instructed to focus on the agent, suggests that it is the agent position and not the patient position that is important in producing this effect. This provides further evidence that the probe word and scene recognition paradigms may be tapping into different types of effects. Nevertheless, these effects may be related. This will be explored in the General Discussion.

CHAPTER 12

GENERAL DISCUSSION

Section 12.1 – Introduction

The goal of this dissertation has been to examine the possibility that transitive sentences produce manuospatial biases, perhaps that the syntactic frame is spatial in nature, as has been suggested elsewhere (e.g., Chatterjee, 2001; Talmy, 2000). I tested this idea using a novel technique inspired by tasks used in the magnitude-space and Simon effect literature (e.g., Dehaene, Bossini, & Giraux, 1993; Gevers, Reynvoet, & Fias, 2003; Rubichi & Nicoletti, 2006), as well as using a scene recognition paradigm similar to that used by Chatterjee, Southwood, and Basilico (1999) and Maas and Russo (2003). Now that I have presented the results of all the experiments, we are in a better position to recognize patterns of effects that have emerged cross-experimentally and approach an answer to the question: is syntax grounded in space? Let us first summarize the findings from all of the experiments, then discuss their various relations, and finally draw some conclusions based on the inter-experimental concordances and discordances.

Section 12.2 – Summary of experimental results

E1 had participants read transitive sentences and judge whether probe words presented to the left and right side of the computer monitor were the subjects or objects of the sentences they had just read, making lateralized button presses. There was an interaction between probe word, probe side, and response hand. This was characterized by the expected pattern of results appearing on the left hand (subjects faster than objects), with a more exaggerated effect on the left side than the right.

E2 repeated the design from E1, changing the nature of the task such that participants judged the gender of the actors in the sentence. I also found an interaction between hand, space, and word, characterized as before with a left hand effect in the expected direction and no effect on the right hand.

E3 employed a go/no-go task, with participants responding to subjects, objects, and the final words of the sentences with a central button press (with right and left hand responding groups). There was a three-way interaction very similar in nature to what was found before: an interaction between word and side on the left hand, but not on the right hand.

E4 looked at whether or not a magnitude-space effect would be observed for novel lists. Order of objects in the list interacted with space, such that first-presented objects were responded to faster on the left relative to second and final objects, and vice versa for the right. Hand did not interact with any other variables.

E5 tested for a syntax-space effect in the audio modality. There was, indeed, an effect, though this interacted with the imageability of verbs unlike the effects observed in previous experiments. The nature of this interaction was such that subject accessibility was affected by imageability on the left hand, not with the left ear but with the right.

E6, returning to the visual modality, investigated the effect of sentence voice on the syntax-space effect. Interestingly, the addition of the voice factor led to separate effects of side and hand, specifically a three-way interaction between side, word, and voice, and another between hand, word, and voice. The nature of these two interactions were somewhat similar, suggesting that hand or side biases only occur for patients and not agents.

E7 removed button pressing from the design, repeating E6 with vocal responses. This was the only experiment not to find any interaction between response side and linguistic factors.

E8 used a crossed hands design in order to further investigate the contribution of the hands in these effects. There was a four-way interaction between side, hand, word, and position. The normal hand position essentially showed a replication of E1, E2, E3 and the active voice condition of E6, while the crossed hand position found no interaction with side: only an interaction between word and hand with faster object responses on the right than the left hand. This experiment also showed that print exposure is important generally to attention, but not necessarily for the syntax-space effect. On the other hand, handedness does seem to be relevant. The main finding was that on the left hand there was a main effect of word (faster subject responses) on the left side, but for the right side, weak right-handers showed less of a difference between subject and object responses than strong right-handers.

E9 shifted to a scene recognition paradigm, where participants read sentences and then confirmed whether or not a scene matched the event the sentence described. Voice was also manipulated. Similar to E6, two separate effects were found: an agent side by voice interaction, and a response hand by voice interaction. The first interaction suggests a benefit to responding to scenes with a left-side agent and right-side patient only following actives. The second interaction suggests response hand does not matter following an active sentence, but following passives, the right hand is much faster than the left.

E10 removed the language task from the design but included English and Arabic groups, having participants indicate which person in a scene was performing the action. For English speakers, the left hand showed a left-side agent bias in contrast to previous experiments showing a *patient* sensitivity to space, but the right hand did not. For Arabic speakers there was no effect of hand or agent side.

Section 12.3 –An effect of action

I have throughout this paper referred to the syntax-space effect, and at this point it is certainly worth reassessing what this term means. So what is the syntax-space effect? Specifically, the syntax-space effect is the reduction in the difference of response times observed between agents and patients when moving from left to right (i.e., the effects from E1, E2, E3, E6, E8, and potentially E9 and E10). Additionally, this effect seems strongest when responses are made using the left hand, when the hands are in a normal, lateralized position, and the agents and patients appear in active voice sentences. Variations to voice, response hand, or response hand positioning, lead to either reductions in the effect, eliminations, or a separation between the involvement of space and hand. The relation of this effect to imagery is not entirely clear, but evidence from E5, E9, and E10 suggest that the syntax-space effect leads to mental imagery biases and as a result may affect how scenes are perceived; however, the syntax-space effect at its core is independent from imagery (evidenced by the lack of interactions with the imageability factor with all of the experiments except E5).

One thing that stands out in this pattern of results is that E7 found no effect, while all of the other experiments (which used the hands) did find effects. Previous research has found that increasing the distance between response hands and stimuli leads to a reduction in the involvement of the action-based magnocellular visual pathway in stimulus processing, while placing the hands on the sides of the computer monitor inhibits object-based parvocellular pathways (Gozli, Ardron, & Pratt, 2014; Gozli, West, & Pratt, 2012). Additionally, affordances of stimuli modulate the interactions between response hand and side, such that the advantage for matching SR spatial dimensions (i.e., the Simon effect) can be eliminated if the affordances of the stimuli (e.g., the handle of a coffee mug) do not match the spatial dimension (Tucker & Ellis, 1998). Other research has also show that these manual action effects interact with language (Davoli et al., 2010), and the experiments presented in this dissertation add to that body of literature, providing an argument for an action-based understanding of syntax independent of imagery, perhaps a framework upon which language-based imagery can be built. This arguments is very much in line with other accounts (Chatterjee, 2001; Kemmerer, 2012; Talmy, 2000) of the relation between language and space, adding to it the importance of the hand in these effects and also modifying the claims about the reasons for the left-to-right preference (both discussed below).

Section 12.4 –Multiple maps

One possible criticism to the syntax-space effect is that it may just be a mental memory map of the words in a sentence. Let us consider this in detail. I will entertain three possible explanations for the syntax-space effect in this argument: 1. a map of causation (i.e., a spatial schematic of actors); 2. a map of pure word order (i.e., a linear list of words in the sentence); 3. a combination of the two explanations. In order to rule out some of these arguments let us look back over the experimental designs used throughout this dissertation. Below are several of the sentence templates used, with capitalized words indicating potential probe words:

S1: AGENT verb PATIENT preposition determiner (adjective) final

S2: AGENT VERB PATIENT preposition determiner (adjective) FINAL

S3: PATIENT was verb by AGENT preposition determiner (adjective) final

S4: AGENT verb PATIENT

S5: PATIENT was verb by AGENT

S1 was used in E1, E2, E5, E6 (active), E7 (active), and E8. S2 was used in E3. S3 was used in E6 and E7 (passive). S4 was E9 (active) and S5 E9 (passive). If participants were developing spatial (or temporal) maps of the sentences with their potential target probes (which were nevertheless presented one word at a time in the center of the screen), these maps might correspond to the following:

S1: XXX …. XXX …. …. …. ….

S2: XXX XXX XXX …. …. …. XXX

S3: XXX …. …. …. XXX …. …. …. ….

S4: XXX …. XXX

S5: XXX …. …. …. XXX

These linear maps show several interesting things. First, in S1 and S2, the patient is never associated with the right side of space when considering all of the words together. Second, the only true rightward words are S2 FINAL, S4 PATIENT, and S5 AGENT. S1 consistently found an effect of a difference between AGENT and PATIENT on the left side, which became reduced or (in E2) reversed on the right. S2 found PATIENTS faster than AGENTS on the right, but no FINAL rightward bias. S3 found no AGENT rightward preference, but a left PATIENT preference. S4 found an AGENT left preference and S5 no AGENT or PATIENT preference. Putting aside S4 and S5 (which used the scene recognition paradigm), the general conclusion is that both causal and word order matter. For example, if only word order mattered, across active sentences there would have been a FINAL right side effect, a leftside AGENT preference, and essentially no PATIENT bias (as it was placed in almost the exact middle of the sentence. On the other hand, if only causal order mattered, the AGENT and PATIENT side biases should not have changed across S1 and S3. It seems instead that the AGENT's resilience to spatial movement suggests a special place in sentence saliency. It also reflects many different types of cross-linguistic word order preferences. For example, recall that the subject is typically the first word in the sentence across languages and also that it is quite often removed without a penalty (indeed, typically with an advantage) to processing (Gelormini-Lezama & Almor, 2011; Yang, Gordon, Hendrick, & Wu, 1999). Also recall that the patient is embedded within the verb phrase of a sentence, and that languages tend to preserve verb-object contiguity (Greenberg, 1963). Conceptually, the patient is the prototypical object of the change of state. This is highlighted by the preference of homesigners to iconically sign actions next to real-world patient referents (Goldin-Meadow, 2005) and also the ergative case marking, in which the subjects of intransitive sentences and the patients of transitive sentences share the same case marking. This state-of-change property of the patient may provide a crucial link with the syntax-space effect and may explain why manipulating the voice of a sentence decouples the interaction between response hand and side which is always apparent in the active voice presented alone.

Thus, it seems that the action-syntax link exists above and beyond mere word order. The link is exaggerated by hand use, and potentially only when the hands are used in a maximally interactive condition (e.g., the syntax-space effect is reduced when only one hand is used or the hands are crossed), leading to increased recruitment of spatial resources. It may be the case that the separate contributions of hand and space may be intertwined in this problem with word and causal order. For example, hand and eye movements are critically linked together (Tseng, Bridgeman, & Juan, 2012; Wilson, 1998). A clinical case named Mrs. D reportedly could not execute reaching movements with her hands to regions of space outside of regions processed via the fovea (Carey, Coleman, & Della Sala, 1997). In addition, hand movement can interfere with saccade generation (Neggers & Bekkering, 2000). It may be then that part of the hand effects observed here come from hand-eye spatial mappings due to word order effects, which modulate the causal order syntax-space effect, and that are further complicated by the fact that only responses engaging the right hemisphere produce these effects. This argument clearly highlights the need to employ eye-tracking in future experiments.

Whereas previous researchers have argued that the left temporal-occipital-parietal junction may be the crucial region in this left-to-right causal order effect (Chatterjee, 2001; Maas & Russo, 2003), the handedness data do not support that theory. If anything, strongly right-handed participants should show greater recruitment of this left hemispheric region (and thus a stronger left-to-right effect), whereas I showed that more ambidextrous individuals showed an increased right-side patient bias than right-handed participants. Annett (1992) reported that left-handed participants (especially male participants) scored higher on the Rey figure task (an indication of visuospatial proficiency) than right-handers and has proposed that right-handedness is associated with a weakening of the right cerebral hemisphere during the course of development in order to facilitate left-hemispheric language development (Annett, 2002). Taking Annett's theory and findings together with the results here leads me to the conclusion that right hemispheric contributions actually underlie the effect and not left hemispheric motion processing regions. This conclusion is further supported by the findings of Zwaan and Yaxley (2003) who found that semantic judgments are made faster when words are displayed in prototypical spatial arrangements, but only when they are presented towards the left visual hemifield and not the right. Finally, even among strong right-handers from our experiments, the syntax-space effect emerges most clearly on the left side and on the left hand. The takeaway of this section seems to be that processing thematic roles through right hemispheric, magnocellular visual pathways lead to a syntax-space effect. This observation should help in developing a more mechanistic account of the syntax-space effect.

Section 12.5 – Imagery?

Is the syntax-space effect based in imagery? My findings suggest that it is independent of imagery; however, it may provide a foundation for generating imagery. The first clue that the syntax-space effect is not a result of conscious imagery is that when these experiments were run in the visual modality, there was no interaction with the imageability ratings of the verbs. In contrast, there was such an interaction in the audio experiment (E5), which again was characterized by an interaction between word, ear, and imageability on the left hand only. I suggested before that visual stimulus depravation encouraged participants to engage in mental imagery when listening to the sentences. Importantly, it was responses to *agent* probes that was impacted by the imagaebility ratings. This is in stark contrast to the results of E1, E2, E3, E6, and E8, which all show differences in *patient* responses across hand and side. The results of E9 can only conclusively support an argument that both agents and patients need to be in their respective prototypical locations; however, in E10, participants were explicitly told to make judgments about the agent, and here there was a clear left-side bias for English speakers using their left hand.

It is difficult to draw a strong conclusion about the effect of imagery without directly manipulating the variable or designing separate experiments where participants are instructed to imagine a sentence or when they are given a secondary visuospatial working memory task preventing them from doing so. I have, of course, mentioned the increased working memory load of passives, and have indeed observed that in passive conditions the syntax-space effect is absent or reduced. However, this explanation is post hoc. In a rating study comparing the imageability of passive and active sentences (all of the stimuli used in these experiments) 212 participants rated that actives were easier to imagine than passives, $\chi^2(1) = 9.63$, $p = 0.002$. This may seem to provide some support to the role of imagery, especially in conjunction with the finding from E5 where removing visuospatial stimuli from the task led to a syntax-space interaction with imageability.

A final point about imagery is that, many verbs involve non-lateral spatial dimensions (e.g., *hang, lift, launch*), and these have been shown to produce their own priming effects (Richardson et al., 2003). These orthogonal spatial characteristics could conceivably override whatever lateral bias a verb may carry with it at this pre-imagery processing stage. Alternatively, the two spatial biases may act together, producing diagonal spatial biases.

Section 12.6 – Future directions

While I have covered a number of areas in this dissertation, now that I have provided evidence for the syntax-space effect, it is important to study it further to get a better understanding of its general nature, including its timing and neural underpinnings. Given the possibility raised by the E5 results that imagery may have some relation with the effect, it will be beneficial to manipulate this variable in a more systematic way. Additionally, previous research has suggested the importance of verb directionality in scene recognition, and this may also prove to be important in the syntax-space effect. For example, within the category of transitive verbs there are subclasses of verbs where on the one hand the subject produces a change of state in the object (stimulus-experiencer; e.g., *Bob angered Jane*) and on the other hand the object produces a change of state in the subject (experiencer-stimulus; e.g., *Jane feared Harold*; Brown & Fish, 1983). It may be the case that between these types of verbs there are differences in how directionality interacts with space. Also, verb semantics in general may be a confound, and if it is true that syntax is spatial in nature, the effects observed throughout this dissertation should hold when participants read sentences where the verbs are replaced by pseudowords (e.g., *Harold zulped Penny*). Regarding methodology, the previous discussion clearly suggests the importance of running eye-tracking studies in order to better understand the scene recognition results, but it would also be beneficial to use this methodology in the probe word studies. This would provide a detailed temporal profile of the effect, as well as the contribution of lateral oculomotor movements in these results. Finally, transcranial magnetic stimulation may be an important method to use in order to test the various neural regions that have been implicated in this work and previous research (e.g., right superior parietal regions, left temporo-parieto-occipital junction). If these regions are crucial in the syntax-space effect, then disruption in their neural activity could potentially reduce the interference associated with (for example) responding to a left side object probe.

Section 12.7 – Conclusion

The relation between the hands and spatial processing seems noncontroversial. Use of the hands guides our understanding of space. Certainly one can lack hands (or any appendage) and still have a concept of space, although perhaps such a concept would be characterized by the movements and timing of objects in the environment: a qualitatively different conception than what would be experienced by one who can interact with and manipulate objects in the environment. Similarly, it is clear also that language can and does exist without the hands, but again, given the rich involvement of the hands in language, the large vocabulary of manual metaphor, the embodiment of comprehension in sensorimotor processes, the co-occurrence of aphasia and apraxia, and the possibility that manual gestures provided a springboard for the evolution of language, a language without hands would also presumably be qualitatively different than one with. Reading is clearly a visuospatial task, and its effects on development are of critical importance. I have shown that in addition to these interactions, syntactic construction involves spatial processing. This does not seem to be a crucial aspect of syntax, although there have been rare reports of the co-occurrence of neglect and aphasia following left-hemispheric temporal and parietal damage (Suchan & Karnath, 2011). Perhaps other, minor spatial deficits are present in aphasics (or vice versa), but the severity of the primary disorder eclipses the presence of the minor one. For example, pseudoneglect may be subtly greater in aphasics, or visual neglect patients may exhibit subtle deficits in comprehending transitivity. Do regions of the brain involved in hand and space mark the remnants of some older system of action performance/comprehension alongside which language developed?

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Appendix A

Items

Table A.1. Experiment 1 items

Wendy thanked Janet after the meal.
Brandy presented Samantha at the gala reception.
Carmella thought about Liza during the war.
Joan avoided Susan for the entire semester.
Jill met Brenda at the elementary school.
Sarah entertained Michelle during spring break.
Danielle adopted Maggie at the municipal court.
Penelope examined Cindy at the dental clinic.
Nicole slapped Valerie during the rehearsal.
Dawn met Stacy on the dance floor.
Brittany annoyed Catherine during biology class.
Julie warned Andrea in the hotel lobby.
Jessica spotted Holly in the weight room.
Stephanie conversed with Alyssa at the conference.
Rachel arrested Marie in the parking lot.
Laura complimented Sandra at the end of the day.
Steve carried Ben down the steep mountainside.
Thomas saw Bill in the checkout lane.
Derek insulted Brad in the shopping mall.
Phil questioned Kyle during the oral exam.
Christopher high-fived Trent after the fight.
Eddie followed Stan from a safe distance.
Troy found Nathan at the movie store.
Fred shoved Ernie at the top of the slide.
Josh called Robert from across the room.
Ethan took Brian to the new theme park.
Andrew abandoned George in the middle of the date.
Ken passed Richard on the way to work.
Abe left Russel at the end of the evening.
Roger photographed Jeff during the wedding reception.

Frank assisted Brandon before bedtime.
Robbie paid Craig once a month.
Dale hired Greg during the winter holiday.
Kirk caught Raymond behind the curtains.
Jane visited Annie in the recovery room.
Emily raised Kate in the small apartment.
Eden recruited Sally for the basketball team.
Beth rejected Kristin after the big argument.
Alexandra pushed Sophia into the cold water.
Alisha fed Amanda with a small teaspoon.
Whitney noticed Krissy at the holiday party.
Marcia brought Amy to the job fair.
Rita invited Joanna to the bridal shower.
Becca positioned Mary next to the statue.
Rebecca recognized Vivian at the high school reunion.
Margaret flattered Suzanne during the dinner party.
Heather contacted Crystal last summer.
Alexis encouraged Betsy throughout the years.
Liz identified Charlotte at the hospital.
Phoebe escorted Katie around the compound.
Jacquelyn greeted Christine outside the movie theater.
Shawn helped William in the empty house.
Adam criticized Harold during the board meeting.
Ryan scolded Henery after the birthday party.
Desmond praised Tom during the long speech.
Nick watched Carl at the train station.
Jacob inspired Neil during the performance.
Martin applauded James at the end of the play.
Bob stopped Matthew in the waiting room.
Eric bowed to Carlos at the end of the show.
Marcus observed Kenneth at the sales event.
Joseph approached Mike in the dining room.
Ted remembered Drew during art class.
Matt interrogated Zack at the police station.
Anthony advised Theodore during the trial.

Table A.2. Experiment 2 items

Wendy thanked Bob after the meal.
Brandy presented Eric at the gala reception.
Joan avoided Ted for the entire semester.
Jill met Pete at the elementary school.
Maggie entertained Paul during spring break.
Danielle adopted Matt at the municipal court.
Penelope examined Anthony at the dental clinic.
Jane visited Ethan in the recovery room.
Emily raised Andrew in the small apartment.
Eden recruited Ken for the basketball team.
Beth rejected Abe after the big argument.
Alexandra pushed Roger into the cold water.
Alisha fed Liam with a small teaspoon.
Whitney noticed Frank at the holiday party.
Marcia brought Robbie to the job fair.
Rita invited Dale to the bridal shower.
Becca positioned Kirk next to the statue.
Janet stopped Matthew before the cliff's edge.
Eva observed Kenneth at the sales event.
Jennifer approached Mike in the dining room.
Susan remembered Drew during art class.
Sarah interrogated Zack at the police station.
Cindy advised Theodore during the trial.
Annie took Brian to the new theme park.
Kate abandoned George in the middle of the date.
Sally passed Richard on the way to work.
Kristin left Russel at the end of the evening.
Sophia photographed Jeff during the wedding reception.
Krissy washed Brandon before bedtime.
Amy paid Craig once a month.
Joanna hired Greg during the winter holiday.
Mary caught Raymond behind the curtains.
Steve carried Nicole down the steep mountainside.
Thomas saw Dawn in the checkout lane.
Derek insulted Brittany in the shopping mall.
Phil questioned Kelly during the oral exam.
Christopher hugged Julie after the fight.
Eddie followed Jessica from a safe distance.
Troy found Stephanie at the movie store.

Fred shoved Rachel at the top of the slide.
Josh called Laura from across the room.
Shawn helped Lucy in the empty house.
Adam criticized Margaret during the board meeting.
Ryan scolded Miriam after the birthday party.
Desmond praised Heather during the long speech.
Nick watched Alexis at the train station.
Jacob inspired Liz during the performance.
Martin applauded Phoebe at the end of the play.
Ben slapped Valerie during the rehearsal.
Bill kissed Stacy on the dance floor.
Brad annoyed Catherine during biology class.
Trent warned Andrea in the hotel lobby.
Stan spotted Holly in the weight room.
Ernie arrested Marie in the parking lot.
Robert complimented Sandra at the end of the day.
Edgar charmed Anna at the music festival.
Jared recognized Vivian at the high school reunion.
Harold flattered Suzanne during the dinner party.
Tom contacted Crystal last summer.
Carl encouraged Betsy throughout the years.
James identified Charlotte at the hospital.
Neil escorted Katie around the compound.
Jeremy greeted Christine outside the movie theater.

Table A.3. Experiment 3 items

Miranda informed Dominic about the concert.
Bailey electrocuted Marcia with the taser.
Kurt located Gale at the wedding ceremony.
Faith taunted Bill with harsh words.
Elizabeth dismissed Alexandra with a warning.
Fredrick belittled Carolina at the business assembly.
Jason described Connor in the article.
David pursued Nora during the fall term.
Grace motivated Andrew during the workout.
Jared prepared Maria for the job interview.
Nadine reassured Darryl after the presentation.
Donald spied Rachel with the binoculars.
Trent welcomed Chase into the new house.
Austin encountered Shelby at the fresh market.
Seth seated Ella next to the television.
Isabelle saved Penelope on Christmas Day.
Sharon banned Marcus from the lecture hall.
Adam astonished Owen during the function.
Mona startled Roger from behind the door.
Cole cornered June under the tree.
Rebecca acknowledged Carmella with a smile.
Chad amazed Max with the strange tale.
Lyle chased Kayla with a bat.
Sarah bothered Luke with a few complaints.
Thelma collected Amber from the station.
Bryce struck Anna with a ski pole.
Beck corrected Hugh during the pop quiz.
Wade accused Kat during the trial.
Carl found Pete with the tracking device.
Nathan served Ashley at the diner.
Carly disregarded Kevin during the funeral.
Blake included Chuck in the acceptance speech.
Eugene intimidated Violet before the soccer championship.
Beatrice hit Samantha with a ruler.
Johnny woke Melissa before work.
Claire disturbed Tyrone during the big match.
Selena ogled Maggie at the backstage affair.
Raymond summoned Suzanna during the lecture.
Penny blinded Carlos with the flashlight.

Danita treated Vivian for smallpox.
Meagan dunked Thomas under the water.
Theodore embarrassed Kimberly on Tuesday.
Russell outperformed Jasmine during the audition.
Jeremy nursed Brandon during the epidemic.
Peter disciplined Fran on the porch.
Kelsey mocked Alyssa during the vacation.
Drew frightened Paige during the ghost story.
Helen scared Jack with a Halloween mask.
Gus addressed Joy duirng the break.
Wayne passed Bree in the foyer.
Timothy pinched Allison during the ballet.
Lily clobbered Paul with a frying pan.
Dennis neglected Arthur during the inauguration.
Duke agitated Eve after practice.
Anne delivered Brett to the banquet.
Louis supported Rose throughout medical training.
Leo fastened Jay into the high chair.
Miriam saluted Olivia with a flag.
Kate surprised James during the Easter brunch.
Finn wanted April for the new position.
Abby humiliated Scott with the personal criticism.
Nick led Josh in the right direction.
Candace poked Griffin with the stick.
Dylan attacked Leah with a knife.
Ruth smacked Gary during the social.
Patrick corrupted Regina during summer camp.
Martha deceived Walter during the card game.
Scarlett transported Stephanie in the helicopter.
Jane nurtured Rita for a long time.
Todd tapped Nancy with the pencil.
Summer videotaped Farrah during the opera.
Howard teased Claudia at the anniversary gathering.
Ellen raised Martin onto the counter.
Patty told Dean about the stray cat.
Eddie badgered Shea about the mess.
Monica offended Victor at the family meal.
William married Madison in the fall.
Justin guarded Chloe in the bomb shelter.
Barbara divorced Lawrence after the accident.
Albert enlisted Glenn into the army.
Wendy thanked Sydney after the recital.
Brandy presented Sophie at the debutante ball.

Liz joined Eva before the debate.
Lisa ambushed Lana after the Thanksgiving feast.
Holly comforted Eliza during the war.
Joan avoided Susan for the entire semester.
Jill confronted Chaz in August.
Hilary entertained Lester during the harvest season.
Mary adopted Neve in December.
Noah examined Cindy on every other Saturday.
Ava slapped Rob during the rehearsal.
Dawn met Stacy three days ago.
Brittany annoyed Catherine throughout the holiday.
Kelly hushed Trudy before the training seminar.
Julie warned Andrea after prom.
Jessica spotted Valerie in the laboratory.
Herbert seduced Sandra in the pantry.
Tara arrested Marie in the parking garage.
Danny complimented Laura in the morning.
Kyle kicked Anita at the music festival.
Ian carried Ben down the steep mountainside.
Drake saw Brandt in the liquor store.
Derek insulted Brad in the shopping mall.
Phil questioned Pam during the oral exam.
Christy high-fived Hannah after the fight.
Faye followed Stan from a safe distance.
Troy discovered Dane at the shop.
Fred shoved Ernie on the playground.
Lauren called Robert from somewhere in Africa.
Grant bombarded Edgar with many questions.
Ethan took Brian to the theme park.
Bryson abandoned George in July.
Ken transferred Tom to another division.
Abe left Ron after nightfall.
Jake photographed Doug during the wedding reception.
Liam endorsed Jeff after the big expo.
Frank assisted Steve before bedtime.
Robbie paid Craig in September.
Dale hired Greg during the winter.
Kirk caught Matt behind the curtains.
Elise visited Annie in the recovery area.
Emily spanked Isaac in the small condo.
Edie recruited Sally for the basketball team.
Suzanne rejected Kristin after the big argument.
Bruce pushed Sophia into the closet.

Alisha fed Amanda with a small teaspoon.
Whitney noticed Krissy at the holiday gala.
Joe brought Amy to the job fair.
Theresa invited Joanna to the bridal shower.
Charlotte positioned Veronica next to the statue.
Lucy reprimanded Mindy in the alleyway.
Victoria lectured Danielle in the hair salon.
Christine recognized Evangeline at the reunion.
Margaret flattered Bethany during the dinner celebration.
Mason protected Karen in the car.
Earl contacted Ike last spring.
Alexis encouraged Betsy over the years.
Robin identified Becca at the hospital.
Phoebe escorted Katie around the compound.
Jacquelyn greeted Jennifer outside the movie theatre.
Shawn helped Lloyd into the back seat.
Michelle forgave Gustavo after a few weeks.
Charles punched Douglas while at college.
Desmond criticized Harold during the hearing.
Ryan scolded Hank after the birthday party.
Brenda praised Richard during the long chat.
Stanley watched Crystal inside the church.
Jacob inspired Trish during the performance.
Nicole applauded Calvin after the musical.
Mark adored Jenn during high school.
Kenneth stopped Matthew in the waiting room.
Eric defended Pablo from the attacker.
Jed observed Bob at the sales event.
Nelson congratulated Jerome after the project meeting.
Joseph approached Michael in the den.
Ted remembered Dirk during math class.
Ronald amused Neal in the crowded bar.
Will pointed Aiden towards the post office.
Erin interrogated Zack at the police headquarters
Anthony scrutinized Heather during the workshop.

Table A.4. Experiment 5 items

Jason described Connor in the article.
Duke agitated Eve after practice.
Edie recruited Sally at the basketball finals.
Barbara pitied Stephanie after the accident.
Dylan attacked Leah in the basement.
Abby humiliated Scott in the break room.
Charlotte groomed Veronica at the nail salon.
Patrick corrupted Regina during summer camp.
Ethan interviewed Brian at the theme park.
Kate surprised James during the brunch.
Monica offended Victor at the family meal.
Selena ogled Maggie at the backstage affair.
Celeste astonished Owen during the function.
Carl found Pete on the hiking trail.
Lyle chased Kayla into the pool.
Troy discovered Dane at the shop.
Kelsey mocked Arthur during the vacation.
Lily clobbered Paul in the kitchen.
Grace motivated Andrew during the workout.
Donald trailed Rachel through the city streets.
Kenneth stopped Matthew in the waiting room.
Emilio spanked Isaac in the small condo.
Scarlett accompanied Lawrence to the safe house.
Claire disturbed Tyrone during the big match.
Timothy pinched Allison during the ballet.
Suzanne rejected Alisha after the big argument.
Fred shoved Ernie on the playground.
Anne elbowed Brett at the banquet.
Brandy presented Sophie at the debutante ball.
Ian carried Ben after the fire.
Isabelle rescued Penelope from the burning building.
Derek insulted Brad in the shopping mall.
Carly ignored Kevin during the funeral.
Ryan scolded Hank after the play.
Liam endorsed Jeff at the big expo.
Louis supported Rose throughout medical school.
Seth saw Ella on the television.
Summer videotaped Farrah during the opera.
Sharon banned Marcus from the lecture hall.

Danita treated Vivian at the pharmacy.
Joseph approached Michael in the den.
Helen scared Jack at the campfire.
Albert beat Glenn during the weightlifting competition.
Thelma bullied Chuck in the schoolyard.
Blaine mentioned Amber in the acceptance speech.
Gus addressed Joy duirng the break.
Holly comforted Eliza during the war.
Chad amazed Max during the fishing trip.
Bryce struck Anna at the skating rink.
Wayne nudged Bree in the foyer.
Jared consulted Maria at the tax office.
Elise visited Annie in the recovery room.
Drake hailed Brandt in the liquor store.
Grant soothed Edgar at the zoo.
Drew frightened Paige at the movie theater.
Kristin fed Amanda at lunchtime.
Johnny woke Melissa before work.
Robin identified Katie at the hospital.
Miriam saluted Olivia during the parade.
Trent welcomed Chase into the new house.
Lynn electrocuted Marcia at the power plant.
Beck corrected Hugh during the pop quiz.
Penny blinded Carlos on the highway.
Sarah bothered Luke at the dance club.
Meagan soaked Thomas at the birthday party.
Kurt located Gale at the wedding ceremony.
Ruth smacked Gary during the social.
Mona startled Roger in the funhouse.
Ted pestered Dirk during math class.
Candace poked Griffin in the emergency room.
Brittany annoyed Catherine at the holiday gathering.
Finn fired April after the incident.
Peter berated Fran during basic training.
Eugene intimidated Violet before the soccer championship.
Wade accused Kat during the trial.
Victoria repulsed Danielle in the hair salon.
Jane nurtured Rita for a long time.
Nathan served Carmella at the diner.
Elizabeth dismissed Alexandra from the meeting.
Austin harrassed Shelby at the market.
Jacquelyn greeted Evangeline outside the movie theatre.
Abe left Ron at the penitentiary.

Liz joined Eva before the debate.
Jessica spotted Valerie in the laboratory.
Dennis neglected Alyssa during the inauguration.
Eric defended Pablo during the prison riot.
Jacob inspired Trish during the performance.
Erin interrogated Zack at the police headquarters
Michelle forgave Gustavo after a few weeks.
Herbert seduced Sandra in the pantry.
Christy lauded Hannah after the fight.
Earl contacted Ike last spring.
Suzanna summoned Raymond during the lecture.
Jill confronted Chaz in the laundry room.
Miranda hugged Dominic at the concert.
Julie warned Andrea after the prom.
Faith taunted Bill during recess.
Will numbed Aiden at the dental clinic.
Jed observed Bob at the sales event.
Noah examined Cindy at the free clinic.
William pacified Madison after the crisis.
Sean helped Lloyd at the fundraiser.
Leo embraced Jay at the award ceremony.
Anthony scrutinized Heather during the workshop.
Nora pursued David during the fall term.
Kelly hushed Trudy before the training seminar.
Desmond criticized Charles during the hearing.
Danny complimented Laura in the morning.
Rebecca acknowledged Ashley at the football game.
Whitney noticed Krissy at the holiday gala.
Stanley watched Crystal inside the church.
Ellen kissed Martin on the cheek.
Joan avoided Susan for the entire semester.
Margaret flattered Bethany during the dinner celebration.
Kyle kicked Pam at the music festival.
Bruce pushed Sophia into the closet.
Phoebe escorted Becca around the compound.
Phil questioned Anita during the oral exam.
Howard teased Claudia at the annual gathering.
Mark adored Jenn during high school.
Tara arrested Marie in the parking garage.
Faye spied Stan in the crowd.
Bryson abandoned George in the parking lot.
Nicole applauded Calvin after the musical.
Martha deceived Wendy during the card game.

Mason protected Karen in the car.
Dawn ambushed Lana after the feast.
Brenda praised Richard during the long chat.
Hilary entertained Lester at the karaoke bar.
Eddie badgered Shea in the mess hall.
Joshua selected Amy at the job fair.
Ken shushed Tom at the board meeting.
Dale hired Greg after the job search.
Nelson congratulated Jerome after the project meeting.
Beatrice hit Samantha at the stop sign.
Robbie paid Craig at the checkout counter.
Nadine reassured Darryl after the carnival.
Patty emailed Dean during the lecture.
Alexis encouraged Betsy in the locker room.
June cornered Cole under the tree.
Frank assisted Steve before bedtime.
Jeremy nursed Brandon during the epidemic.
Justin guarded Chloe in the bomb shelter.
Ronald amused Neal in the crowded apartment.
Jake photographed Doug during the wedding reception.
Jasmine outperformed Russell at the audition.
Carolina belittled Fredrick at the business assembly.
Mary uplifted Neve during the winter months.
Nick led Josh to the amusement park.
Walter thanked Sydney after the recital.
Lauren phoned Robert from somewhere in Africa.
Kirk caught Matt behind the curtains.
Christine recognized Jennifer at the reunion.
Theodore embarrassed Kimberly during the camping trip.
Theresa pranked Joanna at the bridal shower.
Lisa tickled Stacy at daycare.
Lucy reprimanded Mindy in the alleyway.
Harold punched Douglas at the bar.
Ava slapped Rob during the rehearsal.
Todd sterilized Nancy before the operation.

Table A.5. Experiment 6 items

Active	Passive
Austin harassed Shelby at the market.	Shelby was harassed by Austin at the market.
Jason described Connor in the article.	Connor was described by Jason in the article.
Duke agitated Eve after practice.	Eve was agitated by Duke after practice.
Edie recruited Sally at the basketball finals.	Sally was recruited by Edie at the basketball finals.
Barbara pitied Stephanie after the accident.	Stephanie was pitied by Barbara after the accident.
Dylan attacked Leah in the basement.	Leah was attacked by Dylan in the basement.
Abby humiliated Scott in the break room.	Scott was humiliated by Abby in the break room.
Charlotte groomed Veronica at the nail salon.	Veronica was groomed by Charlotte at the nail salon.
Patrick corrupted Regina during summer camp.	Regina was corrupted by Patrick during summer camp.
Ethan interviewed Brian at the theme park.	Brian was interviewed by Ethan at the theme park.
Kate surprised James during the brunch.	James was surprised by Kate during the brunch.
Monica offended Victor at the family meal.	Victor was offended by Monica at the family meal.
Selena ogled Maggie at the backstage affair.	Maggie was ogled by Selena at the backstage affair.
Celeste astonished Owen during the function.	Owen was astonished by Celeste during the function.
Carl found Pete on the hiking trail.	Pete was found by Carl on the hiking trail.
Lyle chased Kayla into the pool.	Kayla was chased by Lyle into the pool.
Troy discovered Dane at the shop.	Dane was discovered by Troy at the shop.
Kelsey mocked Arthur during the vacation.	Arthur was mocked by Kelsey during the vacation.
Lily clobbered Paul in the kitchen.	Paul was clobbered by Lily in the kitchen.
Grace motivated Andrew during the workout.	Andrew was motivated by Grace during the workout.
Donald trailed Rachel through the city streets.	Rachel was trailed by Donald through the city streets.
Kenneth stopped Matthew in the waiting room.	Matthew was stopped by Kenneth in the waiting room.
Emilio spanked Isaac in the small condo.	Isaac was spanked by Emilio in the small condo.

Scarlett accompanied Lawrence to the safe house.	Lawrence was accompanied by Scarlett to the safe house.
Claire disturbed Tyrone during the big match.	Tyrone was disturbed by Claire during the big match.
Timothy pinched Allison during the ballet.	Allison was pinched by Timothy during the ballet.
Suzanne rejected Alisha after the big argument.	Alisha was rejected by Suzanne after the big argument.
Fred shoved Ernie on the playground.	Ernie was shoved by Fred on the playground.
Anne elbowed Brett at the banquet.	Brett was elbowed by Anne at the banquet.
Brandy presented Sophie at the debutante ball.	Sophie was presented by Brandy at the debutante ball.
Ian carried Ben after the fire.	Ben was carried by Ian after the fire.
Isabelle rescued Penelope from the burning building.	Penelope was rescued by Isabelle from the burning building.
Derek insulted Brad in the shopping mall.	Brad was insulted by Derek in the shopping mall.
Carly ignored Kevin during the funeral.	Kevin was ignored by Carly during the funeral.
Ryan scolded Hank after the play.	Hank was scolded by Ryan after the play.
Liam endorsed Jeff at the big expo.	Jeff was endorsed by Liam at the big expo.
Louis supported Rose throughout medical school.	Rose was supported by Louis throughout medical school.
Seth saw Ella on the television.	Ella was seen by Seth on the television.
Summer videotaped Farrah during the opera.	Farrah was videotaped by Summer during the opera.
Sharon banned Marcus from the lecture hall.	Marcus was banned by Sharon from the lecture hall.
Danita treated Vivian at the pharmacy.	Vivian was treated by Danita at the pharmacy.
Joseph approached Michael in the den.	Michael was approached by Joseph in the den.
Helen scared Jack at the campfire.	Jack was scared by Helen at the camp fire.
Albert beat Glenn during the weightlifting competition.	Glenn was beaten by Albert during the weightlifting competition.
Thelma bullied Chuck in the schoolyard.	Chuck was bullied by Thelma in the schoolyard.
Blaine mentioned Amber in the acceptance speech.	Amber was mentioned by Blaine in the acceptance speech.
Gus addressed Joy duirng the break.	Joy was addressed by Gus during the break.
Holly comforted Eliza during the war.	Eliza was comforted by Holly during the war.

Chad amazed Max during the fishing trip.	Max was amazed by Chad during the fishing trip.
Bryce struck Anna at the skating rink.	Anna was struck by Bryce at the skating rink.
Wayne nudged Bree in the foyer.	Bree was nudged by Wayne in the foyer.
Jared consulted Maria at the tax office.	Maria was consulted by Jared at the tax office.
Elise visited Annie in the recovery room.	Annie was visited by Elise in the recovery room.
Drake hailed Brandt in the liquor store.	Brandt was hailed by Drake in the liquor store.
Grant soothed Edgar at the zoo.	Edgar was soothed by Grant at the zoo.
Drew frightened Paige at the movie theater.	Paige was frightened by Drew at the movie theater.
Kristin fed Amanda at lunchtime.	Amanda was fed by Kristin at lunchtime.
Johnny woke Melissa before work.	Melissa was woken by Johnny before work.
Robin identified Katie at the hospital.	Katie was identified by Robin at the hospital.
Miriam saluted Olivia during the parade.	Olivia was saluted by Miriam during the parade.
Trent welcomed Chase into the new house.	Chase was welcomed by Trent into the new house.
Lynn electrocuted Marcia at the power plant.	Marcia was electrocuted by Lynn at the power plant.
Beck corrected Hugh during the pop quiz.	Hugh was corrected by Beck during the pop quiz.
Penny blinded Carlos on the highway.	Carlos was blinded by Penny on the highway.
Sarah bothered Luke at the dance club.	Luke was bothered by Sarah at the dance club.
Meagan soaked Thomas at the birthday party.	Thomas was soaked by Meagan at the birthday.
Kurt located Gale at the wedding ceremony.	Gale was located by Kurt at the wedding ceremony.
Ruth smacked Gary during the social.	Gary was smacked by Ruth during the social.
Mona startled Roger in the funhouse.	Roger was startled by Mona in the funhouse.
Ted pestered Dirk during math class.	Dirk was pestered by Ted during math class.
Candace poked Griffin in the emergency room.	Griffin was poked by Candace in the emergency room.
Brittany annoyed Catherine at the holiday gathering.	Catherine was annoyed by Brittany at the holiday gathering.
Finn fired April after the incident.	April was fired by Finn after the incident.

Peter berated Fran during basic training.	Fran was berated by Peter during basic training.
Eugene intimidated Violet before the soccer championship.	Violet was intimidated by Eugene before the soccer championship.
Wade accused Kat during the trial.	Kat was accused by Wade during the trial.
Victoria repulsed Danielle in the hair salon.	Danielle was repulsed by Victoria in the hair salon.
Jane nurtured Rita for a long time.	Rita was nurtured by Jane for a long time.
Nathan served Carmella at the diner.	Carmella was served by Nathan at the diner.
Elizabeth dismissed Alexandra from the meeting.	Alexandra was dismissed by Elizabeth from the meeting.
Todd sterilized Nancy before the operation.	Nancy was sterilized by Todd before the operation.
Jacquelyn greeted Evangeline outside the movie theatre.	Evangeline was greeted by Jacquelyn outside the movie theatre.
Abe left Ron at the penitentiary.	Ron was left by Abe at the penitentiary.
Liz joined Eva before the debate.	Eva was joined by Liz before the debate.
Jessica spotted Valerie in the laboratory.	Valerie was spotted by Jessica in the laboratory.
Dennis neglected Alyssa during the inauguration.	Alyssa was neglected by Dennis during the inauguration.
Eric defended Pablo during the prison riot.	Pablo was defended by Eric during the prison riot.
Jacob inspired Trish during the performance.	Trish was inspired by Jacob during the performance.
Erin interrogated Zack at the police headquarters	Zack was interrogated by Erin at the police headquarters.
Michelle forgave Gustavo after a few weeks.	Gustavo was forgiven by Michelle after a few weeks.
Herbert seduced Sandra in the pantry.	Sandra was seduced by Herbert in the pantry.
Christy lauded Hannah after the fight.	Hannah was lauded by Christy after the fight.
Earl contacted Ike last spring.	Ike was contacted by Earl last spring.
Suzanna summoned Raymond during the lecture.	Raymond was summoned by Suzanna during the lecture.
Jill confronted Chaz in the laundry room.	Chaz was confronted by Jill in the laundry room.
Miranda hugged Dominic at the concert.	Dominic was hugged by Miranda at the concert.
Julie warned Andrea after the prom.	Andrea was warned by Julie after the prom.
Faith taunted Bill during recess.	Bill was taunted by Faith during recess.
Will numbed Aiden at the dental clinic.	Aiden was numbed by Will at the dental clinic.

Jed observed Bob at the sales event.	Bob was observed by Jed at the sales event.
Noah examined Cindy at the free clinic.	Cindy was examined by Noah at the free clinic.
William pacified Madison after the crisis.	Madison was pacified by William after the crisis.
Sean helped Lloyd at the fundraiser.	Lloyd was helped by Sean at the fundraiser.
Leo embraced Jay at the award ceremony.	Jay was embraced by Leo at the award ceremony.
Anthony scrutinized Heather during the workshop.	Heather was scrutinized by Anthony during the workshop.
Nora pursued David during the fall term.	David was pursued by Nora during the fall term.
Kelly hushed Trudy before the training seminar.	Trudy was hushed by Kelly before the training seminar.
Desmond criticized Charles during the hearing.	Charles was criticized by Desmond during the hearing.
Danny complimented Laura in the morning.	Laura was complimented by Danny in the morning.
Rebecca acknowledged Ashley at the football game.	Ashley was acknowledged by Rebecca at the football game.
Whitney noticed Krissy at the holiday gala.	Krissy was noticed by Whitney at the holiday gala.
Stanley watched Crystal inside the church.	Crystal was watched by Stanley inside the church.
Ellen kissed Martin on the cheek.	Martin was kissed by Ellen on the cheek.
Joan avoided Susan for the entire semester.	Susan was avoided by Joan for the entire semester.
Margaret flattered Bethany during the dinner celebration.	Bethany was flattered by Margaret during the dinner celebration.
Kyle kicked Pam at the music festival.	Pam was kicked by Kyle at the music festival.
Bruce pushed Sophia into the closet.	Spohia was pushed by Bruce into the closet.
Phoebe escorted Becca around the compound.	Becca was escorted by Phoebe around the compound.
Phil questioned Anita during the oral exam.	Anita was questioned by Phil during the oral exam.
Howard teased Claudia at the annual gathering.	Claudia was teased by Howard at the annual gathering.
Mark adored Jenn during high school.	Jenn was adored by Mark during high school.
Tara arrested Marie in the parking garage.	Marie was arrested by Tara in the parking garage.
Faye spied Stan in the crowd.	Stan was spied by Faye in the crowd.

Bryson abandoned George in the parking lot.	George was abandoned by Bryson in the parking lot.
Nicole applauded Calvin after the musical.	Calvin was applauded by Nicole after the musical.
Martha deceived Wendy during the card game.	Wendy was deceived by Martha during the card game.
Mason protected Karen in the car.	Karen was protected by Mason in the car.
Dawn ambushed Lana after the feast.	Lana was ambushed by Dawn after the feast.
Brenda praised Richard during the long chat.	Richard was praised by Brenda during the long chat.
Hilary entertained Lester at the karaoke bar.	Lester was entertained by Hilary at the karaoke bar.
Eddie badgered Shea in the mess hall.	Shea was badgered by Eddie in the mess hall.
Joshua selected Amy at the job fair.	Amy was selected by Joshua at the job fair.
Ken shushed Tom at the board meeting.	Tom was shushed by Ken at the board meeting.
Dale hired Greg after the job search.	Greg was hired by Dale after the job search.
Nelson congratulated Jerome after the project meeting.	Jerome was congratulated by Nelson after the project meeting.
Beatrice hit Samantha at the stop sign.	Samantha was hit by Beatrice at the stop sign.
Robbie paid Craig at the checkout counter.	Craig was paid by Robbie at the checkout counter.
Nadine reassured Darryl after the carnival.	Darryl was reassured by Nadine after the carnival.
Patty emailed Dean during the lecture.	Dean was emailed by Patty during the lecture.
Alexis encouraged Betsy in the locker room.	Betsy was encouraged by Alexis in the locker room.
June cornered Cole under the tree.	Cole was cornered by June under the tree.
Frank assisted Steve before bedtime.	Steve was assisted by Frank before bedtime.
Jeremy nursed Brandon during the epidemic.	Brandon was nursed by Jeremy during the epidemic.
Justin guarded Chloe in the bomb shelter.	Chloe was guarded by Justin in the bomb shelter.
Ronald amused Neal in the crowded apartment.	Neal was amused by Ronald in the crowded apartment.
Jake photographed Doug during the wedding reception.	Doug was photographed by Jake during the wedding reception.
Jasmine outperformed Russell at the audition.	Russell was outperformed by Jasmine at the audition.

Carolina belittled Fredrick at the business assembly.	Fredrick was belittled by Carolina at the business assembly.
Mary uplifted Neve during the winter months.	Neve was uplifted by Mary during the winter months.
Nick led Josh to the amusement park.	Josh was led by Nick to the amusement park.
Walter thanked Sydney after the recital.	Sydney was thanked by Walter after the recital.
Lauren phoned Robert from somewhere in Africa.	Robert was phoned by Lauren from somewhere in Africa.
Kirk caught Matt behind the curtains.	Matt was caught by Kirk behind the curtains.
Christine recognized Jennifer at the reunion.	Jennifer was recognized by Christine at the reunion.
Theodore embarrassed Kimberly during the camping trip.	Kimberly was embarrassed by Theodore during the camping trip.
Theresa pranked Joanna at the bridal shower.	Joanna was pranked by Theresa at the bridal shower.
Lisa tickled Stacy at daycare.	Stacy was tickled by Lisa at daycare.
Lucy reprimanded Mindy in the alleyway.	Mindy was reprimanded by Lucy in the alleyway.
Harold punched Douglas at the bar.	Douglas was punched by Harold at the bar.
Ava slapped Rob during the rehearsal.	Rob was slapped by Ava during the rehearsal.

Table A.6. Experiment 9 and 10 verbs

Bandage	Film	Scare	Stab
Bite	Kick	Scratch	Strangle
Brush	Poke	Shoot	Tap
Chase	Pull	Shove	Tickle
Dress	Punch	Slap	Trip

Appendix B

Verb Ratings

Table B.1. Imageability ratings of verbs used throughout the experiments

Verb	Rating	Verb	Rating
abandon	1.85333	intimidate	2.31333
accompany	2.022	invite	2.10667
accuse	2.1	join	2.2
acknowledge	2.00667	kick	1.4
address	2.56	kiss	1.3
adopt	2.48667	laud	3.49333
adore	2.40667	lead	2.08667
advise	2.38	leave	2
agitate	2.37333	lecture	2.09333
amaze	2.42667	locate	2.22
ambush	2.17333	marry	1.62
amuse	2.32667	meet	2.44
annoy	2.16	mention	2.33333
applaud	1.43333	mock	2.04667
approach	1.79333	motivate	2.1
arrest	1.46667	neglect	2.50667
assist	2.34	notice	2.26667
astonish	2.7	nudge	1.67333
attack	1.39333	numb	2.4
avoid	2.19333	nurse	2.30667
badger	2.44667	nurture	2.49
ban	2.37333	observe	2.19333
beat	1.81333	offend	2.40667
belittle	2.72	ogle	3.16667
berate	2.94	outperform	2.42667
blind	1.81	pacify	3.03333
bombard	2.12333	pass	1.89333

bother	2.35	pay	1.98667
bring	2.02667	pester	2.14
bully	1.66	phone	1.94667
call	1.60667	photograph	1.45333
carry	1.47333	pinch	1.50667
catch	1.95333	pity	2.76667
charm	2.30667	point	1.56
chase	1.40667	poke	1.46
clobber	1.8	position	2.08
collect	2.21333	praise	2.33333
comfort	2.10667	prank	2.1
compliment	2.13333	prepare	2.42667
confront	2.14667	present	2.22667
congratulate	2	protect	2.04
consult	2.42667	punch	1.40667
contact	2.35333	pursue	2.64667
corner	2.00667	push	1.47333
correct	2.38667	question	2.26
corrupt	3.03667	raise	2.44
criticize	2.22667	reassure	2.58667
deceive	2.66667	recognize	2.23333
defend	2	recruit	2.39333
deliver	2.21333	reject	2.35333
describe	2.67333	remember	2.9
discipline	2.12667	reprimand	2.52
discover	2.44	repulse	2.88
dismiss	2.47333	rescue	1.7
disregard	2.71333	salute	1.76
disturb	2.42	save	2.56
divorce	2.3	scare	1.51333
dunk	1.48667	scold	1.97333
elbow	1.44	scrutinize	2.64
electrocute	1.62	seat	1.81333
email	1.83333	seduce	2.08
embarrass	2.22	see	1.74
embrace	1.76667	select	2.52667
encounter	2.09333	serve	1.8
encourage	2.56667	shove	1.54
endorse	3.04	shush	1.70667
enlist	2.46667	slap	1.33667
entertain	2.36667	smack	1.40333

escort	1.85333	soak	1.96667
examine	1.86667	soothe	2.48
fasten	1.84333	spank	1.46
feed	1.56333	spot	2.10667
fight	1.62667	spy	1.84667
find	2.1	startle	1.76
fire	2.27333	sterilize	2.3
flatter	2.49333	stop	1.78
follow	1.82	strike	1.62
forget	3.1	summon	2.47333
forgive	2.79333	support	2.74
frighten	1.76667	surprise	1.92667
greet	1.65333	take	2.04667
groom	2.10667	tap	1.44
guard	1.92	taunt	2.22
hail	3.03333	tease	2.08
harass	2.16	tell	2.12667
help	1.85333	thank	2.01333
high-five	1.4	tickle	1.38667
hire	2.4	trail	2.24
hit	1.37333	transfer	2.7
hug	1.41333	transport	1.88667
humiliate	2.25333	treat	2.4
hush	1.87333	uplift	2.92667
identify	2.33333	videotape	1.56667
ignore	2.12	visit	1.80667
include	2.53	wake	1.72667
inform	2.42333	want	3.1
inspire	2.93667	warn	2.28667
insult	2.08	wash	1.61333
interrogate	1.75333	watch	1.84667
interview	1.88667	welcome	2.00667

APPENDIX C

QUESTIONNAIRES

Handedness Questionnaire

Please indicate which hand you prefer for each of the following activities:

	Left hand strongly preferred	Left hand mildly preferred	No preference	Right hand mildly preferred	Right hand strongly preferred
1. Writing					
2. Drawing					
3. Throwing					
4. Using scissors					
5. Brushing teeth					
6. Using knife (without a fork)					
7. Using a spoon					
8. Using a broom (hand on top)					
9. Striking a match					
10. Opening a jar					

Author Recognition Test

Below is a list of names. Some of them are authors of books, and some of them are not. Please put a check mark next to theones that you know for sure are authors. There is a penalty for guessing, so you should check only those names about whichyou are absolutely certain. Thank you.

___Patrick Banville	___Harry Coltheart	___Virginia Woolf	___Tony Hillerman
___Kristen Steinke	___Gary Curwen	___John Landau	___Amy R. Baskin
___Ernest Hemingway	___Herman Wouk	___Toni Morrison	___James Clavell
___Clive Cussler	___Geoffrey Pritchett	___Harriet Troudeau	___Salmon Rushdie
___Hiroyuki Oshita	___Ray Bradbury	___Roswell Strong	___Maryann Phillips
___Kurt Vonnegut	___Jay Peter Holmes	___J.R.R. Tolkien	___Scott Alexander
___Anne McCaffrey	___Christina Johnson	___Margaret Atwood	___Ayn Rand
___Elinor Harring	___Jean M. Auel	___Seamus Huneven	___Alex D. Miles
___Sue Grafton	___Judith Stanley	___Harper Lee	___Margaret Mitchell
___Lisa Woodward	___Gloria McCumber	___Chris Schwartz	___Leslie Kraus
___David Harper Townsend	___James Joyce	___Walter LeMour	___Ralph Ellison
___Anna Tsing	___Robert Ludlum	___Alice Walker	___Sidney Sheldon
___T.C. Boyle	___Larry Applegate	___Elizabeth Engle	___ Brian Herbert
___Jonathan Kellerman	___Keith Cartwright	___T.S. Elliot	___Sue Hammond
___Cameron McGrath	___Jackie Collins	___Marvin Benoit	___Jared Gibbons
___F. Scott Fitzgerald	___Umberto Eco	___Joyce Carol Oates	___Michael Ondaatje
___A.C. Kelly	___David Ashley	___Jessica Ann Lewis	___Thomas Wolfe
___Peter Flaegerty	___Jack London	___Nelson Demille	___Jeremy Weissman
___Kazuo Ishiguro	___Seth Bakis	___Arturo Garcia Perez	___Willa Cather
___Jane Smiley	___Padraig O'seaghdha	___S.L. Holloway	___J.D. Salinger
___James Patterson	___E.B. White	___John Irving	___ Antonia Cialdini
___Martha Farah	___Giles Mallon	___Stephen Houston	___ Lisa Hong Chan
___Craig DeLord	___Raymond Chandler	___Marcus Lecherou	___Samuel Beckett
___Nora Ephron	___Isabel Allende	___Valerie Cooper	___Beatrice Dobkin
___Ann Beattie	___Amy Graham	___Tom Clancy	___Wally Lamb
___Stewart Simon	___Marion Coles Snow	___Vladimir Nabokov	___Katherine Kreutz
___Danielle Steel	___George Orwell	___Pamela Lovejoy	___James Michener
___Dick Francis	___Maya Angelou	___Vikram Roy	___William Faulkner
___Ted Mantel	___Bernard Malamud	___Saul Bellow	___Isaac Asimov
___I.K. Nachbar	___John Grisham	___Stephen King	___Lindsay Carter
___Judith Krantz	___Erich Fagles	___Elizabeth May Kenyon	___Paul Theroux
___Thomas Pynchon	___Walter Dorris	___Frederick Mundow	___Francine Preston
___Wayne Fillback	___Gabriel Garcia Marquez		

Reading habits survey

For each question below, please answer as best you can by circling one of the numbers on the scale. Higher numbers indicate more of something, for example time or enjoyment.

1. Compared to other college students, how much time do you spend reading all types of materials?

   1 2 3 4 5 6 7

2. Compared to the reading material of other college students, how complex do you think your reading material is?

   1 2 3 4 5 6 7

3. Compared to other college students, how much do you enjoy reading?

   1 2 3 4 5 6 7

4. Compared to other college students, how fast do you normally read?

   1 2 3 4 5 6 7

5. Compared to other college students, when reading at your normal pace, how well do you understand the reading material?

   1 2 3 4 5 6 7