Peri-Personal Space and the Representation of Quantity: Two Types of Re-Use Responsible for Motor and Spatial Compatibility Effects

Andrea Sell
PERI-PERSONAL SPACE AND THE REPRESENTATION OF QUANTITY:
TWO TYPES OF RE-USE RESPONSIBLE FOR MOTOR AND SPATIAL COMPATIBILITY EFFECTS

By

ANDREA SELL

A dissertation submitted to the Department of Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Degree Awarded:
Summer Semester, 2011
The members of the committee approve the dissertation of Andrea Sell defended on May 3, 2011.

_______________________________________
Michael Kaschak  
Professor Directing Dissertation

_______________________________________
Paula Gerson  
University Representative

_______________________________________
Colleen Kelley  
Committee Member

_______________________________________
Jon Maner  
Committee Member

_______________________________________
Wally Boot  
Committee Member

The Graduate School has verified and approved the above-named committee members.
This dissertation is dedicated to Barbara and Jary Sell.
ACKNOWLEDGEMENTS

The work and thought that went into this dissertation and degree would not have been possible without the many people that have helped me in some way throughout my time in graduate school. Particular thanks to my advisor, Michael Kaschak, from whom I have learnt a great deal, and who has, most importantly, helped me to develop and refine my ideas into manageable and controlled experiments. Also to my committee members, Jon Maner, Colleen Kelley, Wally Boot and Paula Gerson, whose helpful suggestions and comments encouraged me to explore more diversified possibilities with my research. My lab mates, Jackie Coyle, Tim Kutta and John Jones, for informative discussions and fun times. In particular, Jackie Coyle, whose companionship and lunchtime camaraderie I wouldn’t have traded for the world. To all of my friends, for coffee discussions, outdoors trips, frisbee games, late night cookie baking, and general support and encouragement. And lastly, to my loving and supportive fiancé Saul, whose steadfast faith in my abilities propelled my achievements. Thank you.

Andrea Sell

Florida State University

May 2011
# TABLE OF CONTENTS

List of Tables ............................................................................................................................... viii
List of Figures ................................................................................................................................ ix
Abstract ........................................................................................................................................... x

1. INTRODUCTION ................................................................................................................................. 1
   1.1 Concrete Representation .................................................................................................................. 1
   1.2 Abstract Representation ................................................................................................................... 2
   1.3 Space in Representation ................................................................................................................ 3
   1.4 Cortical Reuse .............................................................................................................................. 3
   1.5 Categorical and Semantic Usage of Peri-Personal Space ............................................................ 5
   1.6 Overview of Experiments .............................................................................................................. 7

2. SEMANTIC SET OVERVIEW .............................................................................................................. 8

3. EXPERIMENT 1 ...................................................................................................................................... 10
   3.1 Method ............................................................................................................................................ 10
      3.1.1 Participants .............................................................................................................................. 10
      3.1.2 Materials ............................................................................................................................... 10
      3.1.3 Apparatus ............................................................................................................................ 10
      3.1.4 Procedure .............................................................................................................................. 10
      3.1.5 Keyboard Orientation .......................................................................................................... 11
   3.2 Design and Analysis ..................................................................................................................... 12
   3.3 Results .......................................................................................................................................... 13

4. EXPERIMENT 2 ...................................................................................................................................... 16
   4.1 Method ............................................................................................................................................ 16
      4.1.1 Participants .............................................................................................................................. 16
      4.1.2 Materials ............................................................................................................................... 16
      4.1.3 Apparatus ............................................................................................................................ 16
      4.1.4 Procedure .............................................................................................................................. 16
      4.1.5 Keyboard Orientation .......................................................................................................... 16
   4.2 Design and Analysis ..................................................................................................................... 16
   4.3 Results .......................................................................................................................................... 16
   4.4 Analysis Across Experiments 1 & 2 ............................................................................................. 19

5. EXPERIMENT 3 ...................................................................................................................................... 21
   5.1 Method ............................................................................................................................................ 21
      5.1.1 Participants .............................................................................................................................. 21
      5.1.2 Materials ............................................................................................................................... 21
      5.1.3 Apparatus ............................................................................................................................ 21
      5.1.4 Procedure .............................................................................................................................. 21
      5.1.5 Keyboard Orientation .......................................................................................................... 21
   5.2 Design and Analysis ..................................................................................................................... 21
   5.3 Results .......................................................................................................................................... 22
REFERENCES ..............................................................................................................................60

BIOGRAPHICAL SKETCH .........................................................................................................65
LIST OF TABLES

1 Results of Experiment 1...........................................................................................................15
2 Results of Experiment 2...........................................................................................................18
3 Results of Experiments 1 and 2 compared.............................................................................20
4 Results of Experiment 3...........................................................................................................24
5 Results of Experiment 4..........................................................................................................33
6 Results of Experiment 5..........................................................................................................39
7 Results of Experiment 6..........................................................................................................43
## LIST OF FIGURES

1. Keyboard Orientation for Experiment’s 1, 2, & 3.................................................................11
2. Results, Experiment 1........................................................................................................14
3. Results, Experiment 2........................................................................................................17
4. Results, Experiment 3........................................................................................................23
5. Diagram of Procedure, Experiment 4..................................................................................30
6. Results, Experiment 4........................................................................................................32
7. Diagram of Procedure, Experiment 5..................................................................................35
8. Results, Experiment 5, 700 SOA.......................................................................................37
9. Results, Experiment 5........................................................................................................38
10. Results, Experiment 6........................................................................................................42
The representation of locations and movement in peri-personal space (the space directly in front of the torso) has been hypothesized to be important in the representations of abstract concepts, most notably quantity and time. Presumably, spatial and motor response compatibility effects (interactions between stimuli referring to the abstraction, and the spatial location of a response button) are due to shared representations between real space and metaphorical space. However, the bulk of these types of effects are not explained by one general theory as to the re-use of circuits responsible for perception and movement of peri-personal space during representation and comprehension. In this paper, I propose and test the idea that two types of re-use underlie spatial response compatibility effects pertaining to the representation of quantity. To test the idea that two types of re-use are responsible for different sets of spatial-response compatibility effects, I use the same representation domain, quantity, to contrast the directional differences, and directional flexibility (or lack there-of) that each type predicts. Results indicate that semantic understanding of quantity elicits spatial compatibility effects only on the up-down axis, which is the one used in the conceptual metaphor, while tasks that do not tap into the semantic understanding of quantity can adopt the left-right axis as a convenient spatial schematic organizational tool. These results support the conclusion that, 1) space, or at least, spatial representation is used in processing language about quantity and 2) the uses the spatial representations differ, depending on the task.
CHAPTER 1
INTRODUCTION

The ability to communicate is one of civilizations greatest drives. Our ability to talk about complex and abstract ideas, communicate plans for the future, and teach each other about the past is arguably one of the most important characteristics of the human species. Ironically, it’s been some fifty-thousand years since humans first began speaking, and we’re only just beginning to understand how language comprehension is accomplished.

1.1 Concrete Representation

To date, there is some evidence that at least concrete concepts are talked about and understood using the same neural processes used in experiences associated with the concept. For example, to understand the sentence, “Bobby kicked a ball,” one can activate sensory-motor information associated with kicking a ball, such as pre-motor codes for kicking and visual system correlates for the shape and color of a ball. Brain areas specific to the senses; such as seeing, hearing, taste, and motoric information are activated when people process language involving those modalities. This occurs for multiple parts of speech (e.g., nouns and verbs) and single words as well as whole sentences (e.g. Kan, Barsalou, Solomon, Minor & Thompson-Schill, 2003; Goldberg, Perfetti & Schneider, 2006; Kemmerer, Castillo, Talavage, Patterson, & Wiley, 2008). Additionally, activating sensory-motor representations during language can both facilitate and interfere with behavioral tasks. For example, words denoting location can guide attention to the directional position associated with a word in some cases, and in others, interfere with detecting stimuli in that location (e.g. “cloud” and “up” position on a computer screen or paper, or “hole” and the “down” position), (Verges & Duffy, 2009; Estes, Verges, & Barsalou, 2008; Bergen, Lindsay, Matlock, Narayanan, 2007; Richardson, Spivey, Barsalou, McRae, 2003). This is also true for motoric information; sentences involving directional movement can, depending on when the stimuli are presented, both facilitate and interfere with responses and attention to that axis. For example, reading a sentence such as “the car approached you,” interferes with simultaneous viewing of black and white visual illusions of movement in that direction. These effects occur when participants see movement, hear movement, or respond by moving (Zwaan, Madden, Yaxley & Aveyard, 2004; Kaschak, Madden, Therriault, Yaxley, Aveyard, Blanchard, & Zwaan, 2005; Meteyard, Bahrami, Vigliocco, 2007; Kaschak, Zwaan,
Aveyard & Yaxley, 2006; Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006, Aravena, Hurtado, Rivero, Cardona, Ibanez, 2010; Gentilucci & Gangitano, 1998; Borreggine & Kaschak, 2006; Kaschak & Borreggine, 2008; Taylor & Zwaan, 2008; Bub & Masson, 2010). Thus, there is quite a bit of evidence that understanding concrete language and concepts involves the use of the sensory-motor system.

1.2 Abstract Representation

Comprehension of abstract language is little more difficult to explain using an approach based on reactivation, or simulation, of concepts for understanding. Abstractions do not have the same characteristics that something concrete would have. It’s easy to see how we can use motor representations to understand “run,” but how might one simulate something abstract, like hope, or the future? There is some evidence that abstract sentences such as “Her hopes soared,” are comprehended much the same way as concrete sentences. Lakoff and Johnson (1980) propose that we structure our understanding of abstractions using concrete representations, via metaphor (e.g. Conceptual Metaphor Theory, Lakoff & Johnson, 1980; Gallese & Lakoff, 2005). For example, we may be able to understand the idea that “hopes can soar” the same way we understand that birds can soar. Much of the empirical evidence that supports this view comes from investigations into the “time is space” metaphor, in which we structure our understanding of time in terms of space. Indeed, we typically talk about time in terms of space (e.g. Nunez & Sweetser, 2006; Clark, 1973). Multiple studies have found that priming someone with a spatial schema often changes the way they think of time (Boroditsky, 2000; Matlock, Ramscar & Boroditsky, 2005; Casasanto & Boroditsky, 2008; Merritt, Casasanto & Brannon, 2010). Other metaphors have also received empirical support; such as “categories are containers”, as well as “happy is up,” “power is up,” and “good is to the right,” (Boot & Pecher, 2010; Casasanto & Dijkstra, 2010; Meier, Robinson & Clore, 2004; Casasanto, 2009; Schubert, 2005).
1.3 Space in Representation

Interestingly, many of the metaphors that we use to describe abstractions are spatial metaphors; that is, they either use space as a concrete grounding concept, or the concrete concept used has strong spatial components. For example, time can be represented in front or behind the body, and emotion can be represented on the up-down axis. Additionally, many of the experiments used to investigate sensory-motor activation during language comprehension find spatial or motor compatibility effects. These types of effects are characterized by interactions between a word or sentence referring to the abstraction, and the spatial location (in some cases motoric action to a spatial location) of a response button. For example, after reading a sentence such as “Next month we will have a party,” participants are faster to move their arm and press a button away from their body (Sell & Kaschak, 2011). Spatial and motoric response compatibility effects have been found in a number of domains. Sentences involving abstract transfer produce action compatibility effects (Glenberg & Kaschak, 2002; Glenberg, Sato, Cattaneo, Riggio, Palumbo, Buccino, 2008; Kaschak & Borreggine, 2008; Borreggine & Kaschak, 2006). Sentences involving temporal referents or statements also produce spatial compatibility effects (Sell & Kaschak, 2011; Santiago, Lupianez, Perez & Funes, 2007; and Ulrich & Maieborn, 2010). Finally, quantity related tasks produce spatial compatibility effects (Dehaene, Bossini & Giraux, 1993; Oullet, Santiago, Funes, & Lupianez, 2010; Fischer, Castel, Dodd, & Pratt, 2003; Sell & Kaschak, in prep).

1.4 Cortical Re-Use

Why might space be an important component in abstract representations? And why might comprehension of abstract concepts interact with motor or spatial responses in peri-personal space? One explanation may have to do with the way the language system is structured. A large part of the conceptual metaphor theory is based on the hypothesis that the language system developed by re-using circuits in the mirror neuron system for reaching and grasping in peri-personal space. Hypothetically, the development may have gone something like this: the re-use started with an imitation system for grasping and developed into a simple hand-sign communication system (e.g. Arbib, 2008; Rizzolati, Sinigaglia & Anderson, 2008; Gallese & Lakoff, 2005). This eventually led to a protolanguage which included manual, facial and vocal communication (Arbib, 2005). It has since expanded into a system of distributed networks, ranging from the pre-motor cortex to the visual and the motor cortex (e.g. Pulvermuller, 1999).
These distributed systems across the sensory-motor cortices allow us to easily represent sensory-motor information in concrete simulation. Not only do distributed systems across sensory-motor cortices allow for the simulation of concrete information, it also allows for the simulation of abstract information through the concrete representations. For example, we can metaphorically use concrete simulations such as “I looked up,” to understand abstractions, such as “I’ve always looked up to my father.” Importantly, if this developmental progression is accurate, it would mean that the structure of the language and conceptual system is still very much attuned to pathways for reaching and grasping in the sensory motor cortex. And, to link the pathways devoted to reaching and grasping to ones devoted to perception and representation of peri-personal space is not a big leap. Because the function of reaching and grasping requires perception of spatial areas near the hand and arm, motor pathways used in reaching and grasping are strongly connected to parietal areas involved with spatial perception, particularly areas specific for representing object locations and action goals in peri-personal space (e.g. Gallese & Lakoff, 2005, Arbib, 2008). Additionally, spatial locations around the body and actions in that space are heavily represented in the cortex (e.g. Graziano & Alflalo, 2007). This means we have a large number of circuits devoted to this space. Thus, the representation of peri-personal space is well coded for, and can provide a stable and convenient structure with which to use in representation and simulation. This conjecture implies the metaphorical use of space in representation may be due to the ease in which we can represent and simulate the actual space in front of our torso. Thus, we see frequent use of spatial schemas in representations, and especially those of abstractions. Because of this, we see a number of spatial compatibility effects, such as; sentences involving abstract transfer (Glenberg & Kaschak, 2002; Glenberg et al, 2008; Glenberg, Sato, Cattaneo, Riggio, Palumbo, Buccino, 2008; Kaschak & Borreggine, 2008; Borreggine & Kaschak, 2006), sentences involving temporal referents or statements (Sell & Kaschak, 2011; Santiago, Lupianez, Perez & Funes, 2007; and Ulrich & Maieborn, 2010). Lastly, quantity related tasks produce spatial compatibility effects (Dehaene, Bossini & Giraux, 1993; Ouellet, Santiago, Funes, & Lupianez, 2010; Fischer, Castel, Dodd, & Pratt, 2003; Sell & Kaschak, in prep).

In sum, several lines of work suggest that peri-personal space, and actions within this space, can be a used during language comprehension. However, a few important questions remain unanswered. The first concerns the different types of effects found in this area. Some
effects are restricted to actions (such as reaching) to a spatial location (Glenberg & Kaschak, 2002; Glenberg et al, 2008; Glenberg, Sato, Cattaneo, Riggio, Palumbo, Buccino, 2008; Kaschak & Borreggine, 2008; Borreggine & Kaschak, 2006), and others are only present when the task requires an explicit categorical response (Ulrich & Maieborn, 2010; Dehaene, Bossini & Giraux, 1993) In some cases, they can arise automatically during reading (Sell & Kaschak, 2011), but in other cases they require top-down control (Ristic, Wright, & Kingstone, 2006). Can they all be chalked up to one mechanism of re-use, or are there multiple mechanisms that contribute to a privileged peri-personal space?

### 1.5 Categorical and Semantic Usage of Peri-personal Space

There seems to be more than one way to use peri-personal space. The effects reviewed above can be categorized not only in terms of concrete or abstract simulations, but also by the kind of task produced the effects. Some of the tasks involve attentional tasks (Torralbo, Santiago & Lupianez, 2006; Ulrich & Maienborn, 2010, Santiago, Lupianez, Perez & Funes, 2007; Dehaene, Bossini & Giraux, 1993); others involve a semantic component (Sell & Kashack, 2011; Glenberg & Kaschak, 2002). For example, almost all of the spatial response compatibility effects found on the right-left axis involve a task that forces the participant to make a categorical judgment response. In the canonical SNARC effect studies, participants are asked to judge the magnitude of a number in comparison to another number. If the number is larger, they are asked to press a button on the right, if it is smaller, they are asked to press a button on the left (Dehaene, Bossini & Giraux, 1993) Likewise, temporal spatial compatibility effects are only found on the left-right axis when participants are making a categorical judgment about the temporal nature of the sentence (Santiago, Lupianez, Perez & Funes, 2007; and Ulrich & Maieborn, 2010). When participants are not asked to judge a temporal aspect of the sentence, the spatial compatibility effect disappears (Ulrich & Maieborn, 2010). However, a few of the spatial response compatibility effects that have been documented so far do not involve a categorical judgment. For example, Sell and Kaschak (2011) found that while reading sentences involving future or past temporal referents, such as “next month we will go to the park,” participants are faster to move away from their body to press a button for future statements, and faster to move toward their body to press a button for past statements. So far, it seems that the spatial response compatibility effects that do not involve a categorical judgment usually follow the linguistic metaphor in terms of the spatial location associated with the concept. For example,
some of our preliminary data regarding sentences about quantity, such as “more chickens are in
the yard,” show a spatial response compatibility effect for the up-down, but not for the left-right
axis. Are these types of effects different? Should these studies continue to be grouped together
or do they involve different types of neural re-use?

Rather than try to reconcile these types of effects into one theory of spatial
representation, perhaps it is best to delineate how peri-personal space can be used in multiple
ways. The two apparent types of spatial and action response compatibility effects we are seeing
may be due to two different types of neural re-use. According to Anderson (2010) re-use can
follow more than one form. That is, we may be using pathways developed for perceiving and
acting in peri-personal space in two functionally different ways. The two mentioned by
Anderson (2010) that I believe are at work here are 1) re-use supporting functional inheritance,
and 2) re-use supporting semantic inheritance. The first refers to the re-use of an attentional
mechanism in the left inferior parietal sulcus hypothesized to be important in shifting spatial
attention (Hubbard et al 2005; Walsh, 2003). When anything that can be linearly ordered, such as
numbers, time, quantity, etc, is laid out in a spatial arrangement (such as numbers along a
number line), the mechanism for shifting spatial attention can be re-used by shifting attention on
this line for use in numerical cognition (e.g Anderson, 2010; Hubbard et al, 2005; Walsh, 2003;
Dehaene & Cohen, 2007). This type of mechanism might explain why some spatial compatibility
effects only arise in the service of making explicit judgments (e.g Fischer, Castel, Dodd, &
Pratt, 2003; Hubbard et al, 2005). The second type of re-use that is perhaps driving some spatial
compatibility effects is re-use which supports semantic inheritance. This type of re-use is
implicated in linguistically based mappings. It is the kind of re-use referred to by Gallese and
Lakoff (2005) in the Conceptual Metaphor theory and implies shared neural substrates between
concept and metaphorical mapping. In semantic re-use, abstract representations rely on sharing
the structure of concrete representation, and are therefore much less flexible than that of an
attentional shifting mechanism. This is the type of re-use which would account for spatial
compatibility effects during reading that match the linguistic metaphor (such as the future/front,
past/back or more/up, less/down), and do not involve a categorical response judgment. However,
it is important to note that both of these types of re-use have the potential to make use of parietal
areas responsible for perception and movement in peri-personal space, and therefore, both types
of re-use would predict spatial and motor compatibility effects in peri-personal space.
One way to experimentally differentiate between the semantic use of peri-personal space and an attentional/categorical use is to contrast the directional differences, and directional flexibility (or lack there-of) that each type predicts. Take, for example, the representation of quantity. Semantically, quantity should be arrayed vertically, with larger numbers corresponding to increasing height (e.g. *My work is piling up; Student enrollment dropped this year*), while categorically, quantity could be represented on the left-right axis, much like a number line (e.g. Langston, 2002; Dehane et al, 1993). There is some evidence to support both types of representation. Lakoff and Johnson (1980) provide linguistic analyses indicating that English speakers use a “more is up/less is down” metaphor to structure thought about quantity. As evidence for this claim, Langston (2002) demonstrated that participants were slower to read sentences that violated the *more is up* metaphor (e.g., *He placed Sprite above Coke because it had less caffeine*). Likewise, other behavioral work on the representation of number and quantity suggests that individuals can use the right-left axis in order to think about number and quantity, such as in the canonical SNARC effect (e.g., Dehaene et al., 1993). Narrowing down the type of task that elicits spatial response compatibility effects on specific axis can potentially help characterize and differentiate the two types of re-use that may be borrowing pathways responsible for moving and perceiving in peri-personal space.

1.6 Overview of Experiments

In this study, I investigate the potential that two types of neural re-use are the basis of spatial compatibility effects in peri-personal space. To do this, I compare and contrast spatial response compatibility effects related to quantity in terms of semantic use, and attentional use. The first set of experiments test for semantic re-use regarding the representation of quantity by having participants read short stories involving quantity concepts. The second set of experiments test spatial shifts of attention regarding the representation of quantity by using a dot probe task, a spatial response compatibility test with a categorical task, and a line bisection task.
CHAPTER 2

SEMANTIC SET OVERVIEW

The first set of experiments test for semantic re-use. In these experiments, which I will refer to as the “semantic set,” participants read stories that contain sentences related to quantity (e.g., More/Less runs were being scored this game) and simply pressed a button located in a certain spatial location (up, down, left, and right) after each sentence. They were asked to think about the story in a way that will allow them to correctly answer comprehension questions at the end. Importantly, the task used with these experiments did not ask participants to make a categorical judgment about the stimuli, and therefore tested automatic spatial or action related schema, and did not force participants to use space in an organizational way. In Experiment 1 and 2, participants read the story on the computer screen. The third experiment is very similar to the first two, however participants heard the stories read to them rather than reading it on the computer screen.

In Experiment 1 of the semantic set, participants used response keys aligned on the up-down axis in order to perform the reading task. In Experiment 2 and 3, the response keys were aligned on the left-right axis. The work of Lakoff and Johnson (1980) and Langston (2002) suggests that the up-down axis (more is up) should be recruited to understand sentences about quantity information, and thus it should be possible to observe both spatial and motor response compatibility effects on this axis while reading sentences containing quantity information. For example, understanding the concept (or a sentence) regarding “more” should elicit faster responses on the “Up” position, while sentences regarding “Less” should elicit faster responses in the “Down” position. Likewise, spatial response compatibility effects regarding quantity have been observed on the left-right axis (less is left; more is right; Hubbard et al., 2005), however these effects are usually observed in the context of a categorical judgment task (e.g., Ouellet, Santiago, Funes, & Lupianez, 2010; Fischer, Castel, Dodd, & Pratt, 2003; Hubbard et al, 2005). This set of experiments uses a reading task independent of a categorical judgment task, and thus, overall, I expect spatial response compatibility effects to follow the linguistic metaphoric mapping (more is up). Experiment 3 of the semantic set is almost identical to Experiments 1 and 2, however, participants heard the sentences instead of reading them on the computer screen. Strong left to right spatial biases have been found in cultures that read from the left to the right
across a page (e.g. Chatterjee, Southwood, Basilico, 1999; Maass & Russo, 2003; Chan & Bergen, in press; Dobel, Diesendruck & Bolte, 2007; Spalek & Hamman, 2005). The left-to-right movement associated with reading a passage induces a strong spatial bias, and may interfere with use of the left to right axis during representation. In order to disallow participants from attending to the left-right axis on the basis of reading a passage, the third experiment included an auditory presentation of the stories.
CHAPTER 3

EXPERIMENT 1

Comprehension of Quantity Information on the Up-Down Axis

3.1 METHOD

3.1.1 Participants.

52 undergraduate psychology students participated in experiment 1. All participants were right-handed (self-reported) and spoke English as their native language.

3.1.2 Materials.

Four short stories were adapted from Speer and Zacks (2005). Each story contained 25 sentences. Nineteen of the sentences in each story were filler items, and did not contain any quantity information. The remaining six sentences were critical items (More/Less runs were being scored this game). Each sentence had a more and less version. I created two counterbalanced lists of stimuli, such that an item appeared in one version (e.g., more) on the first list, and in the opposite version (e.g., less) on the second list. I also counterbalanced story order, so that each story appeared as the first, second, third, or fourth story an equal number of times across participants.

3.1.3 Apparatus.

For this Experiment, I created a response device from a standard QWERTY keyboard. I covered the entire keyboard in heavy dark blue folder paper. I then attached plastic blocks to the “A” key and the “6” key (of the number pad) to raise the keys above the folder paper and to make larger for easier button pressing. I then covered the “A” button with pink paper and the “6” button with yellow paper. Thus the only keys visible to the participant during the experiment were one large pink button, and one large yellow button.

3.1.4 Procedure.

Stories were presented to the participant’s sentence-by-sentence (either on the screen, or through headphones). Participants pressed either the pink or yellow button (depending on counterbalance condition) when they saw a central fixation symbol. They were then instructed to hold down the button until they were done reading the sentence. When they were done reading, they were instructed to lift off the designated button, and press the other button.
Halfway through, a message appeared on the screen indicating they would be switching response modes. After this message, participants would press and hold down the opposite button to read the sentence. For the movement condition, participants pressed both keys with their right hand and pointer finger. For the no-movement condition, participants responded by holding their left-hand on the appropriate button to read the sentence, while their right (dominant) hand was positioned over the other response button. A set of four yes/no, comprehension questions followed each story. To avoid alerting the participant to the quantity items, these questions were based on the filler items of the experiment, and never asked about any type of quantity.

3.1.5 **Keyboard Orientation.**

In Experiment 1, the keyboard was attached to a stand next to the monitor, so that it was positioned up, end to end, on the desk (see Figure 1). The keyboard was not moved during the experiment.

![Figure 1: Keyboard Orientation for Experiment's 1, 2, & 3](image-url)
3.2 Design and Analysis

The main analysis carried out on each data set (including experiments 4, 5 & 6) is a mixed models regression. This analysis was used instead of a repeated measure analysis of variance for two main reasons. First, this analysis is becoming increasingly popular when examining psycholinguistic data (e.g. Quene & Bergh, 2008; Baayen, Davidson & Bates, 2008). And second, mixed effects modeling is more powerful than the basic GLM for psycholinguistic data because it allows items and subjects each to be random factors that are crossed, instead of one nested in the other’s model. This subsequently allows the analysis to include both factors in one model, which gives the analysis more power (e.g. Quene & Bergh, 2008).

In both the Movement and No Movement conditions of the first set of experiments, the dependent variable was reading time, or the duration of time that participants held down the first key before releasing the key so that the second key could be pressed to move to the next sentence. The data was prepared for analysis in three phases. First, to eliminate preemptive responses (i.e., the participants lifted off the key too early) and obvious outliers, any response times less than 500 msec and greater than 5000 msec were eliminated. Word length was added to the model to control for length of sentence. We then eliminated any remaining response times that were more than 2 standard deviations from each participants’ mean response time in each cell of the design.

The data from this experiment were analyzed with participants and items crossed in an HLM analysis. The following additional variables were specified in the model: Direction (Left/Right or Up/Down), Quantity (More/Less), Word Length (either in characters or ms), Movement (Move or NoMove) and the interaction of Direction and Quantity. This basic model was used for all experiments in the Semantic Set. Additionally to avoid issues with collinearity, all numerical, non-binary variables were grand-mean centered.
3.3 Results

The results of the mixed-effects model for Experiment 1 are presented in Table 1, and Figure 2. The main result of the HLM analysis in Experiment 1 is a significant interaction between Direction and Quantity \(t(1153)=-2.51, p=.01\). Follow up analyses reveal that responses are faster for Less sentences on the Down location \(t(579)=2.691, p=.008\), while responses are marginally faster for More sentences on the Up location \(t(574)=-1.855, p=.065\). The addition of Movement to the model was not significant \(t(1153)=-0.38, p=.71\), showing that the interaction between Quantity and Direction was not affected by whether or not the participant moved to respond. Additionally, there was a main effect for direction, \(t(1153)=2.70, p=.01\). No other effects were significant.
Figure 2: Results of Experiment 1
Table 1

Results of Experiment 1

Mixed-effects model results

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2351.70</td>
<td>71.86</td>
<td>32.72</td>
<td>1153.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Characters</td>
<td>36.12</td>
<td>3.54</td>
<td>10.20</td>
<td>1153.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Direction</td>
<td>125.37</td>
<td>46.45</td>
<td>2.70</td>
<td>1153.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Quantity</td>
<td>23.86</td>
<td>46.65</td>
<td>0.51</td>
<td>1153.00</td>
<td>0.61</td>
</tr>
<tr>
<td>Quantity by Direction</td>
<td>-193.31</td>
<td>77.02</td>
<td>-2.51</td>
<td>1153.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Movement</td>
<td>-28.49</td>
<td>75.45</td>
<td>-0.38</td>
<td>1153.00</td>
<td>0.71</td>
</tr>
</tbody>
</table>
CHAPTER 4

EXPERIMENT 2

Comprehension of Quantity Information on the Left-Right Axis

4.1 Method

4.1.1 Participants.

52 undergraduate psychology students participated in experiment 1. All participants were right-handed (self-reported) and spoke English as their native language.

4.1.2 Materials.

The materials used in Experiment 2 came from Experiment 1. See above for details.

4.1.3 Apparatus.

The Apparatus used in Experiment 2 was also the same as that used in Experiment 1.

4.1.4 Keyboard Orientation.

The orientation of the keyboard apparatus in Experiment 2 was on the left-right axis. The pink key was aligned with a midline mark on the desk, so that the pink key was also at midline of the participant (see Figure 1). Half of the subjects started with the yellow key to the right of the pink key, and the other half started with the yellow key to the left of the pink key. Halfway through the experiment, the experimenter flipped the keyboard around 180 degrees so that the yellow key was on the opposite side of the pink key from the beginning of the experiment.

4.1.5 Procedure.

The procedure in Experiment 2 was the same as in Experiment 1. See above for details.

4.2 Design and Analysis

The design and analysis of experiment 2 matched that of Experiment 1. The same variables were used in the same model type. See above for details.

4.3 Results

The results of the mixed-effects model for Experiment 2 are presented in Table 2, and Figure 3. The interaction between Direction and Quantity was not significant [t(1093)=1.24, p=.22]. The addition of Movement was also not significant [t(1093)=-1.29, p=.20]. No other effects were significant.
Figure 3: Results of Experiment 2
Table 2  
*Results of Experiment 2*  

**Mixed-effects model results**

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2401.00</td>
<td>72.91</td>
<td>32.94</td>
<td>1093.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Characters</td>
<td>41.49</td>
<td>4.20</td>
<td>9.88</td>
<td>1093.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Direction</td>
<td>17.86</td>
<td>53.37</td>
<td>0.34</td>
<td>1093.00</td>
<td>0.74</td>
</tr>
<tr>
<td>Quantity</td>
<td>-81.92</td>
<td>53.33</td>
<td>-1.54</td>
<td>1093.00</td>
<td>0.13</td>
</tr>
<tr>
<td>Quantity by Direction</td>
<td>108.83</td>
<td>87.67</td>
<td>1.24</td>
<td>1093.00</td>
<td>0.22</td>
</tr>
<tr>
<td>Movement</td>
<td>-110.18</td>
<td>85.56</td>
<td>-1.29</td>
<td>1093.00</td>
<td>0.20</td>
</tr>
</tbody>
</table>
4.4 Analysis Across Experiments 1& 2

Because of the start difference between Experiment 1 and 2, and the goal of axis comparison, the data from both Experiment 1 and Experiment 2 were included in the mixed effect model.

The results for this analysis are presented in Table 3. The same model was used for the previous two experiments, however Movement (Move vs. NoMove) and Axis (Left/Right or Up/Down) was added as a level 2 to the interaction term. Movement was not significant \(t(2252)=-1.244, p=.214\), and therefore taken out of the model to better examine the effect of Axis, which was significant \(t(2252)=2.04, p=.04\). The interaction of Quantity and Direction was also significant, \(t(2252)=-2.40, p=.02\). There was also a main effect for Direction, \(t(2252)=2.07, p=.04\). No other effects were significant.
Table 3

Results of Experiment 1 & 2 compared

Mixed-effects model
results

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2376.91</td>
<td>57.36</td>
<td>41.44</td>
<td>2252.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Characters</td>
<td>38.72</td>
<td>3.78</td>
<td>10.24</td>
<td>2252.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Direction</td>
<td>72.99</td>
<td>35.20</td>
<td>2.07</td>
<td>2252.00</td>
<td>0.04</td>
</tr>
<tr>
<td>Quantity</td>
<td>-29.34</td>
<td>35.28</td>
<td>-0.83</td>
<td>2252.00</td>
<td>0.41</td>
</tr>
<tr>
<td>Quantity by Direction</td>
<td>-137.00</td>
<td>57.05</td>
<td>-2.40</td>
<td>2252.00</td>
<td>0.02</td>
</tr>
<tr>
<td>Axis</td>
<td>115.69</td>
<td>56.75</td>
<td>2.04</td>
<td>2252.00</td>
<td>0.04</td>
</tr>
</tbody>
</table>
CHAPTER 5

EXPERIMENT 3

Comprehension of Quantity Information on the Left-Right Axis with Auditory Presentation

5.1 Method

5.1.1 Participants.

68 undergraduate psychology students participated in experiment 1. All participants were right-handed (self-reported) and spoke English as their native language.

5.1.2 Materials.

The materials used in Experiment 3 came from Experiment 1 & 2. See above for details.

5.1.3 Apparatus.

The Apparatus used in Experiment 3 was also the same as that used in Experiment 1 & 2.

5.1.4 Keyboard Orientation.

The orientation of the keyboard apparatus in Experiment 3 was on the left-right axis. The pink key was aligned with a midline mark on the desk, so that the pink key was also at midline of the participant (see Figure 1). Half of the subjects started with the yellow key to the right of the pink key, and the other half started with the yellow key to the left of the pink key. Halfway through the experiment, the experimenter flipped the keyboard around 180 degrees so that the yellow key was on the opposite side of the pink key from the beginning of the experiment.

5.1.5 Procedure.

The procedure in Experiment 3 was the same as in Experiment 1 & 2, with one exception. Participants heard the sentences instead of reading them from the computer screen.

5.2 Design and Analysis

The design and analysis of Experiment 3 matched that of Experiment 1 & 2. The same variables were used in the same model type. See above for details.
5.3 Results

The results of the mixed-effects model for Experiment 3 are presented in Table 4 and Figure 4. These results follow the HLM of Experiment 2. The interaction between Direction and Quantity was not significant, \[ t(1436) = -1.29, \ p = .20 \]. No other effects were significant.
Figure 4: Results of Experiment 3
Table 4

*Results of Experiment 3*

Mixed-effects model results

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>722.13</td>
<td>75.11</td>
<td>9.61</td>
<td>1436.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Direction</td>
<td>-40.88</td>
<td>75.99</td>
<td>-0.54</td>
<td>1436.00</td>
<td>0.59</td>
</tr>
<tr>
<td>SoundMS</td>
<td>0.05</td>
<td>0.09</td>
<td>0.18</td>
<td>1436.00</td>
<td>0.86</td>
</tr>
<tr>
<td>Quantity</td>
<td>120.30</td>
<td>77.03</td>
<td>1.56</td>
<td>1436.00</td>
<td>0.12</td>
</tr>
</tbody>
</table>
CHAPTER 6

SEMANTIC SET DISCUSSION

The first set of experiments was conducted to potentially provide evidence supporting the idea that circuits used for movement and representation of peri-personal space can be re-used in comprehension to provide a structure on which to simulate and ground abstract, semantic, information. If this is the case, we should see interactions between responses in space and the semantic processing. In this set of experiments, participants read or heard stories which contained quantity information, and then pressed a button in a spatial location which was either semantically congruent or incongruent to the quantity related information. The data from these experiments suggest that spatial and motor compatibility effects are observed when reading sentences about quantity information, and that these effects are observed only on the up-down axis. In sum, congruency effects were observed when participants were asked to press a button in the up or down position after reading a quantity related statement. These effects were present both when participants moved to make their response, and when they had their hands already placed over the response button. Importantly, congruency effects disappeared when participants were asked to press a button in the left or right position after reading. Additionally, given that there were no effects in experiment three, in which participants heard the stories over headphones, rather than read them on the computer, we can dismiss the hypothesis that the left-right movement direction of reading compromised the use of the left-right axis semantic structuring. This pattern of congruency effects on the up-down axis, but not the left-right axis during story comprehension is consistent with the structure of the more is up metaphor discussed by Lakoff and Johnson (1980), as it is important to note that in this case it is the locations (up and down) that matter for expressions that trade on this metaphor rather than movement toward those locations.
CHAPTER 7
ATTENTIONAL SET OVERVIEW

The second set experiments, thus forth called the “Attentional-set,” tested spatial attentional shifts related to quantity representations. A number of previous studies have documented evidence of shifts of spatial attention in relation to number presentation (e.g. Fischer, Castel, Dodd & Pratt, 2003; Calabria & Rossetti, 2005; Fischer, 2001; Hubbard et al, 2005). For example, presentation of a small number (e.g. 1,2, and 3) shifts attention to the left, and presentation of a large number shifts attention to the right, (e.g. 7,8, and 0) (Fischer, Castel, Dodd & Pratt, 2003). For this set of studies, I used methods similar to those studies which test shifts in attention due to numerical primes, but in order for a comparison across tasks in regard to the semantic re-use set, instead of specific numbers; I used the words or phrases closely related to the “more” and “less” concept. Using the same concept base for both sets of experiments allowed the differentiation of semantic re-use spatial compatibility effects and the type of re-use which would allow for attentional shifting in peri-personal space within the concept of quantity change.

Ulrich and Maienborn (2010) found action compatibility effects on the left right axis when participants were asked to judge sentences with regard to whether or not they were 1) sensible, and 2) dealt with the either the past or future. They found participants were faster to respond after reading future statements when the response key was on the right, and faster to respond to past statements when the response key was on the left. However, this effect disappeared when they removed the judgment task regarding the past and future. This seems to be a clear indication that the left right axis is useful only when the spatial array (in Ulrich’s case, a timeline) is brought into attention by the task constraints. In a previous set of experiments, Sell and Kaschak (2011) find spatial compatibility effects without an overt judgment task is used that follow the linguistic metaphor (front-future, back-past), however neither Ulrich and Maienborn (2010) nor Sell and Kaschak (2011) directly compare a categorical task and a semantic task across axis. The attentional-set was also built around the representation of quantity, in order to provide experiments which can be compared to the Semantic-set.

In the first experiment of the Attentional-set (Experiment 4), participants were asked to categorize short phrases as having to do with “more” or “less,” such as, “Less bears” or “More
people,” and respond by pressing either the left or right button. Perhaps when participants are
given a categorical judgment to make, they can use the left-right axis as a “mental-number line”
and shift their attention accordingly in the service of making their decision.

The second experiment (Experiment 5) of the Attent ional-set directly tests for an
attentional shift regarding quantity information. In this task, I used a dot probe to investigate the
spatial (without motor) attention captured by quantity information. A few previous studies have
used a dot-probe to investigate spatial attention capture with regard to the presentation of Arabic
digits (Fischer, Castel, Dodd & Pratt, 2003) and also with words that denote spatial location,
such as sky, or ground (Verges & Duffy, 2009). The second experiment in the attentional-shift
set used the same phrases from the first experiment (i.e. More/Less bears, More/Less water) to
test for spatial attention capture of quantity phrases.

The third experiment (Experiment 6) in the Attentional Set series is similar to the second
in that it tests attentional shift regarding quantity representation. However this experiment is
different in that it involves a motor component. There have been a number of dot-probe studies
investigating attentional shifts with regard to representations; however the results are mixed (e.g.
Bergen, Lindsay, Matlock, & Narayanan, 2007). In the case of quantity and time, the attentional
shift may be more prevalent in a motor task, since Walsh (2003) hypothesized that the motor
system is central to the representation of magnitude. The third experiment in the Attentional Set
involved a line bisection task. Line bisection tasks have been used in previous studies to show
attentional shift in regard to numbers. For example, when asked to draw an “x” at the mid-
section of a line composed of “22222” or “twotwotwotwo..ect…” participants were biased
toward the left as compared to when the line was composed to “99999,” or
“nineninenineninenine…etc,” (Calabria & Rossetti, 2005; Fischer, 2001). This bias is thought to
occur because thinking of the number 2 shifts attention on the “mental number line” to the left,
where low numbers are located; in the same way, thinking of “nine” shifts attention to the right
of the representational number line. In this task, participants were asked to draw an ”l” at what
they feel is the midpoint of a line made up of the word “more” or “less.”

Together, these tasks should show us the nature of quantity representations on the left-
right axis. The auditory categorization task should show us whether the left-right axis can be
used for categorizing representations of “more” and “less.” The dot-probe can show whether or
not the spatial attentional effect is independent of a motor response, and the line bi-section task
can show us whether or not “more” and “less” cause a shift of spatial attention via a motor component.
CHAPTER 8

EXPERIMENT 4

Categorization of Quantity Phrases

8.1 Method

8.1.1 Participants

Forty-Nine people participated in Experiment 4. All participants were right-handed (self-reported) and all spoke English as their native language.

8.1.2 Materials

One-hundred and fifteen words were chosen for use in this experiment. The words were categorized in two ways, abstract, or concrete and uncountable or countable. Each word was made into a test phrases containing one of two quantifying words, “more” or “less,” and the noun. Each phrase had a “more” version and a “less” version. I created two counterbalanced lists of stimuli, such that an item appeared in one version (e.g. more) on the first list and in the opposite version (e.g. less) on the second list. I also randomized item order in the experiment program. See Appendix B for a list of words used.

8.1.3 Apparatus.

This set of experiments uses the same response device as in the first set, with one addition. For the dot-probe task, a regular keyboard was used. This keyboard was placed in the normal keyboard position.

8.1.4 Procedure

Word phrases were presented to the participant phrase by phrase. Participants saw a fixation cross for 500 milliseconds. They then heard the Quantifier (“More” or “Less”) for 700 milliseconds. They then heard the Noun (e.g. “Bears”) and pressed either the right or left button to respond. After the button response, a blank slide appeared for 500ms. After the blank slide, the procedure was presented again for another noun phrase. Button assignment was counterbalanced so that half of the participants pressed the right button for “more” and the left button for “less” for the first half of the experiment, then switched button assignments to left for “more,” and right for “less,” in the second half. The other half of the participants did the opposite. See figure 2 for a diagram of the procedural display.
8.2 Design and Analysis

In the Experiment 4, the dependent variable was the button press RT. The data was prepared in a similar way to that of the semantic experiment set. I first eliminated preemptive responses and obvious outliers by trimming responses less than 500ms and greater than 5000ms. I then eliminated any remaining response times that are more than 2 standard deviations above or below each individual’s mean response time in each cell of the design.

The data from this experiment was analyzed with participants and items crossed. The following additional variables were specified in the model: Response Location (Location; Left/Right), Quantity (More/Less), SoundMS (Milliseconds of the sound bite presented), Countability (Countable/Uncountable), Concreteness (Concrete/Abstract), Wait (wait till end of noun), and the interaction of Quantity and Response Location, as well as the interaction of Quantity, Response Location and Wait.
8.3 Results

The results of the mixed-effects model for Experiment 4 are presented in Table 5 and Figure 6. The major result of the HLM analysis for Experiment 4 is an interaction between Quantity and Response Location, when including Wait (whether or not the participant waited for the end of the noun to respond). The interaction between Quantity and Response Location and Wait was significant \[ t(10737)=12.073, p <.001 \]. More is faster on the Left for No Wait responses \[ t(2225)=4.832, p <0.001 \] and Less is faster on the Right for No Wait responses \[ t(2348)=-4.207, p=0.00 \]. For wait responses, the pattern was similar, but not as significant, More is trending toward being faster on the Left for Wait responses \[ t(3145)=1.824, p=0.068 \], while Less is not significantly faster on the Right in the Wait condition \[ t(2014)=-1.320, p=.187 \]. There were also main effects present for Quantity \[ t(10737)=6.266, p<.001 \] and Side, \[ t(10737)=-4.268, p<0.001 \] and Wait \[ t(10740)=63.313, p=0.00 \]. However, the addition of Concreteness and Countability to the interaction term was not significant. This was true both when each was added alone, and when they were added to the model together \[ p>.221 \].
Figure 6: Results of Experiment 4
Table 5
Results of Experiment 4

*Mixed-effects model results*

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1004.20</td>
<td>36.62</td>
<td>27.42</td>
<td>10737.00</td>
<td>0.00</td>
</tr>
<tr>
<td>WordLength</td>
<td>0.34</td>
<td>0.03</td>
<td>11.74</td>
<td>10737.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Quantity</td>
<td>48.61</td>
<td>7.76</td>
<td>6.27</td>
<td>10737.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Direction (side)</td>
<td>-26.53</td>
<td>6.22</td>
<td>-4.27</td>
<td>10737.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Quantity by Direction</td>
<td>38.44</td>
<td>12.26</td>
<td>3.14</td>
<td>10737.00</td>
<td>0.002</td>
</tr>
<tr>
<td>Concrete</td>
<td>3.90</td>
<td>13.88</td>
<td>0.28</td>
<td>10737.00</td>
<td>0.78</td>
</tr>
<tr>
<td>Countable</td>
<td>-1.79</td>
<td>12.08</td>
<td>-0.16</td>
<td>10737.00</td>
<td>0.88</td>
</tr>
<tr>
<td>Quantity by Direction by</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wait</td>
<td>152.92</td>
<td>12.67</td>
<td>12.07</td>
<td>10737.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
CHAPTER 9

EXPERIMENT 5

Dot Probe after Quantity Phrases

9.1 Method

9.1.1 Participants.

Forty-six people participated in Experiment 5. All participants were right-handed (self-reported) and spoke English as their native language.

9.1.2 Materials.

The same one-hundred and fifteen words used in Experiment 4 were also used in Experiment 5. See above for details.

9.1.3 Apparatus.

A standard keyboard was used in Experiment 5.

9.1.4 Procedure.

This experiment largely followed the method of Fischer, Castel, Dodd and Pratt (2003), with a few exceptions. Participants heard a “more” or “less” phrase, and then performed the typical dot search used in a dot-probe task. Additionally, the location of the dot was in one of two locations (left, or right). The same word phrases used in Experiment 4 was used in Experiment 5. Participants began each trial by looking at a central fixation point flanked by two empty boxes. The fixation point remained on screen for 500ms. Then the quantifier word was played, followed by the noun. After the noun, an inter-stimulus interval wait occurred, which was either 350ms or 700ms. During this time, the empty boxes and fixation point stayed on the screen. Following the inter-stimulus interval, a green dot appeared in one of the boxes. Participants were instructed to press the space bar as soon as they saw a green dot. This screen was presented until participants made a response, or until 2000ms had passed. Some trials were catch trials in which no green dot appeared. After the target dot screen, participants again saw the central fixation flanked by empty boxes for 500ms. See figure 3 for depiction of the procedure for Experiment 5.
9.2 Design and Analysis.

The dot-probe task design and analysis followed closely with the design and analysis of the categorization task. The dependant variable in this case was the amount of time after onset of the stimulus (green dot) to the time of the button press indicating the participant has seen the stimulus. The data was prepared in a similar way to that of the categorization task. I first eliminated preemptive responses and obvious outliers by trimming responses based on two standard deviations above and below the mean of the entire data set. I then eliminated any remaining response times that are more than 2 standard deviations above or below each individual’s mean response time in each cell of the design.

The data in the experiment was used with participants and items crossed in an HLM analysis. The model used Reaction Time of response to seeing the dot as the outcome variable. All models included word length to take into account the amount of time between the quantifying words and the presentation of the dot. Additional variables included in the model
were Quantity (More/Less), Location (Left/Right), the interaction between Quantity and Location, and as level 2’s Concreteness (Concrete/NonConcrete) and Countability (Countable/Uncountable) of the words. Additionally, Time (inter-stimulus interval of 350 or 700) was included.

9.3 Results

The results of Experiment 5 are presented in Table 6, and Figure 8 and 9. The major result of the HLM analysis for Experiment 5 is a facilitation effect that is participants responded faster to the dot if it appeared on the Right after a More phrase, and faster if the dot appeared on the Left after a Less phrase. However, this was only trending in the analysis that did not separate time points [t(8531)=−1.729, p=.083]. Within the time point conditions (an inter-stimulus interval of either 350ms, or 700ms) the interaction was significant at only the inter-stimulus interval of 700ms [t(4300)=−2.275, p=.023]. Such that within the 700 Time point condition (and without Concreteness and Countability added); More was trending towards significance to be faster on the Right [t(2166)=−1.765, p=.077], and Less was not significantly different on either the Right or the Left [t(2135)=0.768, p=.443]. Additionally there was a main effect for Quantity, such that more was slower [t(8531)=1.97, p=.048]. Concreteness and Countability were again not significant [p’s>.2]. However, adding Concreteness and Countability to the interaction term in the 700ms model changed the interaction significance from trending, to significant. Without Concreteness and Countability [t(4302)=−1.79, p=.082]. With Concreteness and Countability added to the interaction term, [t(2164)=−2.292, p=.022]. With Concreteness and Countability added to the model as a level one, the pattern stays the same [P>.08]. With both added as a level 2 to Location, More becomes faster on the Right [t(2164)=−2.292, p=.022], but Less is not significantly faster on the Right or Left [t(2133)=1.416, p=.157]. Since Concreteness was the closest to being significant under the interaction term [t(2164)=1.79, p=.239], follow up analyses were done using Concreteness, at the 700ms Time point. For Concrete items, the interaction of Quantity and Direction was not significant [t(3240)=−0.485, p=.627]. For Abstract items however, the interaction of Quantity and Direction was significant [t(1071)=−2.584, p=.010]. However, follow up analysis reveal that the More items alone are fueling this interaction [t(543)=−2.482, p=.014], while the Less items show no difference between locations [t(527)=1.101, p=.272].
Figure 8: Results of Experiment 5, 700 SOA
Figure 9: Results of Experiment 5
Table 6
Results of Experiment 5

*Mixed-effects model results*

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>418.76</td>
<td>13.51</td>
<td>30.99</td>
<td>8531.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Quantity</td>
<td>7.20</td>
<td>3.17</td>
<td>2.27</td>
<td>8531.00</td>
<td>0.02</td>
</tr>
<tr>
<td>Location</td>
<td>3.71</td>
<td>3.18</td>
<td>1.17</td>
<td>8531.00</td>
<td>0.24</td>
</tr>
<tr>
<td>Time</td>
<td>-5.76</td>
<td>2.24</td>
<td>-2.58</td>
<td>8531.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Quantity by Location</td>
<td>-7.77</td>
<td>4.47</td>
<td>-1.74</td>
<td>8531.00</td>
<td>0.08</td>
</tr>
</tbody>
</table>
CHAPTER 10

EXPERIMENT 6

Line Bisection of Quantity Related Lines

10.1 Method

10.1.1 Participants.

Thirty-six people participated in Experiment 6. All participants were right-handed (self-reported) and all spoke English as their native language.

10.1.2 Materials.

For the line-bisection task, I created three sheets of lines of varying length made of spelled-out words. Each sheet contained lines made of one word, “more”, “less”, and as a control, “desk.” Each page contained twelve lines.

10.1.3 Procedure.

The method of Experiment 3 of the Attentional Set largely followed methods presented in Calabria and Rossetti (2005) and Fischer (2001), with a few exceptions. For this experiment, participants were presented with thirty six strings of words, on three sheets of paper. Each sheet of paper contained 12 strings of the same words. To avoid participants using the page, or other lines to calibrate their responses, each line varied in position and length. The sheets were presented one at a time to the participant, and counterbalanced in order. One sheet contained lines made of the word “more.” Another, lines made of the word “less” and as a control; the third sheet contained lines made of the word “desk.” See Appendix A for sheets. Participants were be asked to mark an “l” at what they think is the midpoint of each line.

10.2 Design and Analysis

The dependent variable in the line bisection task was the difference between the real midpoint of each line, and the location of the “l” marked by participants indicating their estimation of the midpoint. For each line, the real midpoint was measured in millimeters from the start of that line. The point at which the “l” is located was also measured in mm from the start of the line. These were then subtracted. This was done for each sheet, and averaged across participants, and lines. The data from this experiment was analyzed with a within subjects ANOVA with three levels (Word: More vs. Less vs. Desk). Additionally, to control for normal
variability of line-bisection in healthy adults, the data from each participant was entered into a regression analysis with midline difference of target lines as the dependant variable, and midline difference of desk lines as the predictor variable. The residuals from these regressions were saved and used as a dependant variable in the HLM analysis (along with mm difference).

The data from this experiment was analyzed with participants and items (line numbers) crossed in an HLM analysis. The models used either 1) residuals from the Desk sheet, or 2) differences between the real midline and the subjective midline as output variables. Type (More/Less) was the other variable.

10.3 Results

The Results of Experiment 6 are presented in Table 7 and Figure 10. The results of an HLM analysis for Experiment 6 show no effects. Using the residuals from each participants DESK lines, Type (More or Less) was not significantly different \( [t(862)=-.292, p=.771] \). Using the mm difference between the real midline and the subjective midline as the outcome variable showed similar results. More and Less midpoints did not differ significantly \( [t(862)=-.279, p=.780] \).
Figure 10: Results of Experiment 6
Table 7
Results of Experiment 6

*Mixed-effects model results*

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.00</td>
<td>0.42</td>
<td>2.37</td>
<td>862.00</td>
<td>0.02</td>
</tr>
<tr>
<td>Type</td>
<td>-0.09</td>
<td>0.32</td>
<td>-0.28</td>
<td>862.00</td>
<td>0.78</td>
</tr>
</tbody>
</table>
CHAPTER 11

ATTENTIONAL SET DISCUSSION

The second set of experiments was conducted to potentially provide evidence supporting the idea that some of the effects pertaining to use of peri-personal space involve re-use of neural circuits devoted to perception and action in peri-personal space because they are relatively convenient for the task at hand, and not because they provide any sort of semantic grounding for the task (e.g. Anderson, 2010). If this is the case, we should see interactions between responses in space, or spatial cueing, while space is being used in the service of task requirements. In this set of experiments, participants performed one of three types of tasks related in some way to attention to the left right axis while processing quantity related information. The tasks included a categorical judgment with a spatial response, a dot-probe task, and a line bisection task. In sum, participants were faster to categorize More words on the Left, and Less words on the Right, however this was only at early time points. At later time points, this effect disappeared. Additionally, participants were faster to respond to a dot on the Right side of a computer screen after hearing a phrase about “More,” and faster to respond to a dot on the Left of the computer screen after hearing a phrase about “Less.” However, this spatial priming effect was only present in the later time point condition. This effect is consistent with other spatial cueing effects for number and spatial nouns and verbs (i.e. Fischer, Castel, Dodd & Pratt, 2003; Ouellet, Santiago, Funes, & Lupianez, 2010; Ristic, Wright, & Kingston, 2006). The line bisection task did not show differences between conditions. That is, participants were not influenced by quantity words in their bisection of lines. The data from these three experiments suggests processing quantity information can result in shifts of spatial attention. Additionally, the data also suggests that the interaction between the spatial response and quantity information during the categorization task implies some kind of use of the sensorimotor system during the task, however it is unclear the nature of this relationship. The null findings of the line bisection task imply that understanding quantity on a conceptual basis does not necessarily influence spatial-motoric attention.
CHAPTER 12

GENERAL DISCUSSION

The multitude of recent spatial and motor compatibility effects such as those with number, time and transfer (Glenberg & Kaschak, 2002; Glenberg et al, 2008; Glenberg, Sato, Cattaneo, Riggio, Palumbo, Buccino, 2008; Kaschak & Borreggine, 2008; Borreggine & Kaschak, 2006; Sell & Kaschak, 2011; Santiago, Lupianez, Perez & Funes, 2007; Ulrich & Maieborn, 2010; Dehaene, Bossini & Giraux, 1993; Ouellet, Santiago, Funes, & Lupianez, 2010; Fischer, Castel, Dodd, & Pratt, 2003; Sell & Kaschak, in prep) point toward the use of shared representations between real space, and metaphorical space. Since the space around one’s body is well represented cortically, it can provide a convenient and stable structure for which to use as a tool in a couple domains. The re-use of the circuits responsible for spatial perception and movement are presumed to underlie much of the spatial and compatibility effects mentioned above. However, these compatibility effects are not comparable to each other. In some cases, they arise automatically during reading (Glenberg & Kaschak, 2002; Glenberg et al, 2008; Glenberg, Sato, Cattaneo, Riggio, Palumbo, Buccino, 2008; Kaschak & Borreggine, 2008; Borreggine & Kaschak, 2006; Sell & Kaschak, 2011) in other cases they require top-down control or a categorical judgment (Santiago, Lupianez, Perez & Funes, 2007; Ulrich & Maieborn, 2010; Dehaene, Bossini & Giraux, 1993; Ouellet, Santiago, Funes, & Lupianez, 2010; Fischer, Castel, Dodd, & Pratt, 2003). It could be the case that these spatial perception and representation circuits are being re-used in two different ways (e.g. Anderson, 2010). Allowing the circuits that represent movement and space to be used in a couple different ways for higher order cognitive processes could explain the differences in congruency effects in this area. The six studies presented in this paper were designed to use a single concept, quantity, to elicit congruency effects that each type of re-use would predict. The two types of re-use hypothesized to be occurring to account for spatial compatibility effects are semantic re-use and functional re-use. Semantic re-use refers to the reusing of the structure of (in this case) space to ground the understanding of quantity. This is the kind of re-use referred to in the conceptual metaphor theory, in which abstract concepts are understood metaphorically through concrete structures. Functional re-use, on the other hand, refers to the reusing of the ability to shift attention in space, and the use of space as an organizational tool for certain types of tasks.
The first three experiments, the Semantic Set, were designed to explore the use of space in understanding quantity through shared neural substrates between the concept and the grounding domain. The major goal of these three experiments was to test for a lack of flexibility in the congruency effects of a semantic task. Semantic re-use should be relatively inflexible. That is, spatial representations that are used to structure, and to ground, the understanding of concepts should be stable and unchanging. A stable grounding structure allows for shared understanding of abstractions. For example, if two people both understand “more” to be “up,” then it makes sense to say, “My work is piling up quickly,” but it wouldn’t make sense if one person flexibly uses “down” or “to the right” to mean “more,” such as “My work is going down (or, to the right) quickly,” while the other person is using “up” to mean “more.”

Overall, the results of the Semantic Set clearly supported the hypothesis. To see spatial compatibility effects, (such as those in Experiment 1) when participants are reading and understanding sentences about quantity only on the axis that follows the linguistic metaphor, the up-down axis, and not on the left-right axis, (such as in Experiment 2) supports the idea that the spatial representation of “up,” and “down” is being used in the representation of “more” and “less” and this is inflexible and stable.

The second three experiments, the Attentional Set, were designed to explore the use of space in quantity related tasks through shared neural substrates used not for semantic grounding, but shifting spatial attention for the use of categorical tasks. In this case the goal was to show the relative flexibility of spatial congruency effects. That is, the left-right axis did not show congruency effects during the semantic task presumably because the left-right axis is not involved in the conceptual metaphor for quantity. However, functional re-use is not dependant on semantic groundings, and thus can be quite flexible. Therefore the goal for the second set of experiments was to change the type of tasks to demand categorical judgments about the quantity stimuli, instead of a semantic understanding, to show that when the metaphoric understanding does not need to be used for comprehension, the left-right axis is a reasonable spatial tool to use in the task.

In general, the results of the Attentional Set supported the hypothesis. At longer inter-stimulus intervals, the dot-probe task showed spatial attention shifts that interacted with quantity information, implying that the participants adopted spatial schemas for use in the task. We can conjecture that this was not automatic, because this interaction was only seen at longer time
points, consistent with other studies showing that automatic or reflexive attentional shifts to numerical information are seen at inter-stimulus intervals less than 350 milliseconds, and most within 100ms (e.g. Ristic, Wright, & Kingston, 2006; Friesen & Kingstone, 1998). While attentional shifts to numerical information occurring at 700ms after stimulus onset are sensitive top-down factors, such as the mental set that an individual is using to do the task (e.g. a number line or a timeline) (Ristic, Wright & Kingston, 2006; Fischer, 2003; Ouellet, Santiago, Funes, & LupIANeze, 2010).

Additionally, when making categorical judgments participants were able to make use of spatial schema and showed an interaction between space and quantity information. However this interaction was not in the predicted direction. Generally, spatial compatibility effects with numbers and time are assumed to run left-to-right, as does the number line and the timeline. Therefore, it could be expected that quantity, less and more runs from left-to-right as well. Seeing that responses are faster on the left for MORE and on the right for LESS could mean one of two things, either 1) we are seeing an interference effect, or 2) we are seeing evidence of the general flexibility of this type of neural re-use.

The first explanation, an interference effect, is possible, but unlikely. Similar tasks in the literature have not yet produced any interference effects. Categorical judgments involving responses on the right-left axis have generally led to facilitation effects for numbers and for temporal words (Santiago, Lupianez, Perez & Funes, 2007; Ulrich & Maieborn, 2010; Dehaene, Bossini & Giraux, 1993; Ouellet, Santiago, Funes, & Lupianez, 2010; Fischer, Castel, Dodd, & Pratt, 2003). In the case of numbers, the classic SNARC effect is characterized by faster responses to smaller numbers on the left and faster responses to larger numbers on the right. Likewise, in categorical tasks involving time-line judgments, participants are faster to classify a statement as past with a left response, and faster to classify a statement of future with a right response. One possibility is that the timing of the responses could have caused an interference effect. In some literature, asking participants to use both a spatial schema to understand the stimuli while simultaneously forcing a response which relies on the same spatial schema produces interference effects (e.g. Kaschack and Borreggine, 2008; Borreggine & Kaschak, 2006, Taylor & Zwaan, 2008). Indeed, in the present experiment we only see the interaction for early responses. Participants who waited about 1000ms until the noun phrase was complete to respond did not show the interaction. Only responses that were completed sooner than that
showed the interaction, which would seem to support the interference hypothesis. However, in the other categorical studies similar to this one, participants were on about the same procedure time course as the present study. That is, there were able to answer as quickly as they wanted after the target stimuli was presented. That being said, average reaction times in the similar study by Ulrich & Maienborn (2010) are much slower than reaction times in the present experiment, and the sentences are longer as well. Therefore, interference as an explanation for the interaction direction is a possibility, but perhaps not the best explanation.

The second explanation fits better with the general over-all findings of these sets of experiments, as well as adding to the theoretical thrust of the paper. In the case of functional re-use, spatial representations, or the neural circuits responsible for peri-personal spatial representations are re-used for tasks like numerical or temporal categorization tasks mainly because it’s convenient. The attentional shift is useful in the service of the tasks, but other than that, space itself provides no semantic grounding to the conceptual framework of the information. If this is the case, this kind of use should be flexible. That is, it should be relatively easy to change the task to elicit an interaction between space and concept in a number of ways. For example, noticing that many of the numerical dot-probe studies only showed facilitation effects 700ms after presentation of the stimulus, Ristic, Wright, and Kingstone (2006) attributed these shifts of spatial attention to top-down, non-automatic processes. Indeed they found that if they added two other positions to the dot-probe, a Top and Bottom box, in addition to the positions at the Left and Right, the effect disappeared. Similarly, asking participants to imagine a clock face before the seeing the target number completely reversed the effect. This flexibility in the way the space is primed or cued indicates that it is not being used as a strict semantic grounding of the conceptualization, but rather a tool used for the current task. Likewise, the results of the present categorization study reflect this flexibility. In this case, I believe these results support the idea of functional inheritance in that the spatial representations of the space are being re-used in the service of making the categorical judgment; however the spatial representation is not related to the semantic understanding of the concept being judged.

The line bisection task did not reveal an interaction between quantity words and spatial biases. In this case, we may be able to conclude that the words “More” and “Less” do not automatically shift attention to the right or the left, or at least, this shift in attention is not seen in a motoric task. However, the method of the experiment may have contributed slightly to the null
findings. It has been said that “the average bisection errors of healthy adults are often smaller than the pencil tips that generate them” (Fischer, 2001, pg 460). Indeed, the means are going in the correct direction; “More” lines were skewed more to the right than “Less” lines, however both biases were within 1 millimeter on average of the midline, and the standard deviations were at least 3 millimeters on average. So, it may be the case that the differences are there, but too small, and incur too much variation, for any real conclusions to be made about automatic shifts of attention in the line bisection task.

Overall, the pattern of results obtained in these six experiments points toward the conclusion that it is possible that spatial compatibility effects often lumped together into one idea of spatial representation re-use are actually working with the same neural circuits but perhaps in different ways. It is clear that spatial representation can be used in the understanding of quantity information, such that spatial response compatibility effects arise automatically while comprehending quantity statements only in the directional locations which match the metaphor used in the representation. It is also evident that spatial representation can be used in more top-down attention related tasks when the spatial schema provided serves as a handy organizational tool for the task. These two types of effects may reflect different types of re-use of the circuits responsible for representing movements, objects, and the space around the body.
APPENDIX A

Example of Line-Bisection Stimuli

LESLELESLELESLELESLELESLELESLELESLE

LESLELESLELESLELESLELESLELESE

LESLELESLELESLELESLELESLELES

LESLELESLELESLELESLELES

LESLELESLELESLELESLELESLELESLELESLELESLELES

LESLELESLELESLELESLELESLELES

LESLELESLELESLELESLELESLELES

LESLELESLELESLELESLELESLELES

LESLELESLELESLELESLELESLELES
APPENDIX B

Nouns used in Experiments 4 and 5

<table>
<thead>
<tr>
<th>WORD</th>
<th>COUNTABILITY</th>
<th>CONCRETENESS</th>
<th>WORD</th>
<th>COUNTABILITY</th>
<th>CONCRETENESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>air</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td>leather</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>alligators</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>leaves</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>aluminum</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td>lemonade</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>anger</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td>lobsters</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>apples</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>meat</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>bags</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>metal.</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>balloons</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>milk</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>baskets</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>money</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>bears</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>monikers</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>beef</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td>music</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>beetles</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>nature</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>birds</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>oatmeal</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>boats</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>peace</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>books</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>pencils</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>boxes</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>pens</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>bread</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td>phones</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>bricks</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>pillows</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>brushes</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>pipes</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>buildings</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>plates</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>butter</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td>power</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>carrots</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>presents</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>cars</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>purses.</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>cats</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>quiet</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>chairs</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>rain</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>chaos</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td>revenge</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>charity</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td>rice</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>cloth.</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td>rings</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>coal</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td>rocks</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>coffee</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td>safety</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>coins</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>shirts</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>cookies</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>smoke</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>courage</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td>snow</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>cows</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>socks</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>culture</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td>stairs</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>desks</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>steaks</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>dollars</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>steel</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>dolls</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>straws</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>dust</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td>students</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>education</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td>sugar</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>eggs</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>sunshine</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
</tr>
<tr>
<td>electricity</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td>thought</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>elephants</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td>thrills</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
</tr>
<tr>
<td>experience</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>flowers</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>freedom</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>friendship</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>glass</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>guns</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hair</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>heat</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>honey</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>houses</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ice</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>information</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>intelligence</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>jealousy</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>journals</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>justice</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kernels</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>keys</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>knowledge</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tigers</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>toys</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>trees</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>trouble</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>turtles</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vegetables</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>violins</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>water</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wheels</td>
<td>COUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wine</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wool</td>
<td>UNCOUNTABLE</td>
<td>CONCRETE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>work</td>
<td>UNCOUNTABLE</td>
<td>ABSTRACT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C

Stories used in Experiments 1-3

**Story 1 Toby**
Toby was planting a garden in his backyard.
He decided to start by planting vegetables.
(MORE/LESS) wind was blowing this afternoon than usual.
Toby picked up a shovel.
He prepared a few rows for seeds.
He put some seeds in the holes and covered them with dirt.
(MORE/LESS) squirrels had been running through the yard lately.
Toby leaned over to pick a flower.
He took a drink of water from his water bottle.
He thought about putting up a scarecrow to keep the birds away from his garden.
(MORE/LESS) sun was shining today.
Toby thought about getting some tomatoes.
He liked to eat them on sandwiches.
He looked around to find a good tree limb for hanging up a lantern.
(MORE/LESS) dogs were barking.
Toby looked at his lawn.
He needed to buy fertilizer the next time he was at the store.
The lawn had a few bare spots that needed to be fixed.
(MORE/LESS) birds were chirping in the trees.
Toby put some herbs in a planter.
Later he would put it in the window where he could keep an eye on it.
Before he decided to call it quits for the day, he wanted to put in a few rose bushes.
(MORE/LESS) neighbors passed by to say hello.
Toby put away his tools.

**Story 2 Jim**
Jim was a freshman in college who had just received a brand new computer for his birthday.
He opened up a box and started taking out various parts.
(MORE/LESS) parts were included than he thought there would be.
Jim looked at the instructions.
Now that he knew what to do, it was time to get moving on the installation process.
He was happy to see a DVD burner on the computer tower.
(MORE/LESS) people were hanging out around the dorms today.
Jim put the monitor on his desk.
It was a flat screen so it would not take up much space.
He connected a printer cable from the back of the tower into the printer.
(MORE/LESS) music was playing today than normal.
Jim noticed an extra cord on the floor.
He looked at the instructions to see where it went.
Jim wanted to take a break, so he turned on the television to watch the end of a tennis game.

(MORE/LESS) floor activities were happening this week.

Jim ate a candy bar.

He was getting close to being done with his setup.

He took out his keyboard, mouse, and modem.

(MORE/LESS) people brought pets to the dorms this semester

Jim cleaned up his mess.

Now everything was ready to go.

It was time to test the computer.

(MORE/LESS) of his roommates books were lying around today.

Jim called his parents.

He wanted to thank them for sending him such a great computer.

---

Story 3 Rita

Rita was at the airport waiting to get on her flight to visit her sister in London.

She put her jacket on the chair next to her as she sat down.

(MORE/LESS) people brought their kids traveling with them today.

Rita took out a brush from her suitcase.

She was getting anxious to board the plane.

Glancing down at the ticket, she noticed her seat was located in row seven, which was her lucky number.

(MORE/LESS) delays were announced in this airport.

Rita thought she might have to get a snack.

She did not want to be hungry during the flight.

She took out a novel and started to read.

(MORE/LESS) captains had walked by her this hour.

Rita picked up her purse.

She wanted to make sure she had her passport.

She decided to try some lighter reading, so she picked up an issue of People.

(MORE/LESS) cell phones were distracting her now.

Rita looked at her watch.

She hoped they would not be arriving too late.

She checked the voicemail on her cell phone.

(MORE/LESS) people seem to call her when she travels.

Rita saw people getting up from their seats.

Apparently they wanted to walk around before boarding the plane.

She began to feel dehydrated and took out a bottle of water.

(MORE/LESS) people were walking around now.

Rita took out her ticket.

She was finally on her way.

---

Story 4 Bill

Bill arrived at the baseball game and sat down in his seat.

He had brought his glove to the game with the hope that he would catch a foul ball.

(MORE/LESS) people were in the stands than the last game.

Bill put his binoculars on the ground.

He looked up to see when the game was going to start.
He saw the grounds crew raking the dirt.
(MORE/LESS) rain had fallen this week.
Bill could see the players warming up.
The game did not seem to be starting soon.
He looked around and noticed many children in the stands.
(MORE/LESS) vendors were going up and down the stands than usual.
Bill wondered if his team would win.
The home team ran out onto the field and the game began.
Bill wanted to hear the game, so he turned on his radio.
(MORE/LESS) people brought radios with them to the games these days.
Bill put on his glasses.
He wanted to be able to read the scoreboard.
He began to feel warm, so he took off his jacket.
(MORE/LESS) runs were being scored this game.
Bill noticed a drop of rain on his coat.
He realized it was just water from his cup.
He looked up at the plate to see who was batting next.
(MORE/LESS) batters were getting home runs.
The pitcher threw a strike.
The strike ended the game, so Bill picked up all of his things and went home.
APPENDIX D
IRB APPROVAL

Office of the Vice President For Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673 · FAX (850) 644-4392

APPROVAL MEMORANDUM

Date: 2/2/2011

To: Andrea Sell

Address: New Psychology Building
Dept.: PSYCHOLOGY DEPARTMENT

From: Thomas L. Jacobson, Chair

Re: Use of Human Subjects in Research
Representation of Quantity in Language

The application that you submitted to this office in regard to the use of human subjects in the proposal referenced above have been reviewed by the Secretary, the Chair, and two members of the Human Subjects Committee. Your project is determined to be Expedited per 45 CFR § 46.110(7) and has been approved by an expedited review process.

The Human Subjects Committee has not evaluated your proposal for scientific merit, except to weigh the risk to the human participants and the aspects of the proposal related to potential risk and benefit. This approval does not replace any departmental or other approvals, which may be required.

If you submitted a proposed consent form with your application, the approved stamped consent form is attached to this approval notice. Only the stamped version of the consent form may be used in recruiting research subjects.

If the project has not been completed by 1/31/2012 you must request a renewal of approval for continuation of the project. As a courtesy, a renewal notice will be sent to you prior to your expiration date; however, it is your responsibility as the Principal Investigator to timely request renewal of your approval from the Committee.

You are advised that any change in protocol for this project must be reviewed and approved by the Committee prior to implementation of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for
approval by the Committee. In addition, federal regulations require that the Principal Investigator promptly report, in writing any unanticipated problems or adverse events involving risks to research subjects or others.

By copy of this memorandum, the Chair of your department and/or your major professor is reminded that he/she is responsible for being informed concerning research projects involving human subjects in the department, and should review protocols as often as needed to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

This institution has an Assurance on file with the Office for Human Research Protection. The Assurance Number is IRB00000446.

Cc: Michael Kaschak, Advisor
HSC No. 2010.5661
APPENDIX E

CONSENT FORM

Informed Consent Form: Representation of Quantity in Language

I freely and voluntarily consent to be a participant in the research project “Language and Memory.” This research is being conducted by Andrea Sell and Dr. Michael Kaschak at the Department of Psychology, Florida State University.

The purpose of this research is to understand the ways that people’s specific kinds of experience and language processing systems work together during language comprehension. I understand that if I participate in this study, I will be asked to perform one of the following tasks that are checked off below:

___ Reading or listening to short stories or sentences.
___ Taking a memory test for materials presented in the experiment.
___ Drawing a line through a sentence.
___ Judging the sensibility of phrases.

I understand that I must be 18 years of age in order to participate. The total time commitment would be between 30 and 60 minutes, and I will be compensated by receiving either 1) 1 credit point toward my research requirement in General Psychology or 2) extra credit points (if participating for a course other than General Psychology). If I decide to stop participation, I will still be entitled to the research credit or extra credit point. All the data collected from the experiment will be confidential to the extent provided by law and will not be connected to me by name or other identifying information. In addition, my name will not appear in any results. No individual responses will be reported in any presentations or publications that come from this work. Only group findings will be reported. I understand that all data relevant to the study will be kept in a locked file cabinet or on a password protected computer in the researchers’ laboratory space for 10 years (until September, 2021).

I understand that the experiment does not in any way constitute a risk to me.

I understand that there are benefits for participating in this research project. First, I may gain insight into how different kinds of experience shape the way that I learn, understand, and use language. I will also be providing researchers with valuable insight into these issues.

I understand that this consent may be withdrawn at any time without prejudice, penalty or loss of benefits to which I am otherwise entitled. I have been given the right to ask and have answered any inquiry concerning the study. Questions if any, have been answered to my satisfaction.

I understand that I may contact Andrea Sell, Florida State University, Department of Psychology, Psychology, for answers to questions about this research or my rights. Group results will be sent to me upon my request. If I have questions about my rights as a subject/participant in this research, or feel I have been placed at risk, I can contact the Chair of

FSU Human Subjects Committee Approved on 2/01/11. Void after 1/31/12. HSC# 2010.3861
the Human Subject Committee, Institutional Review Board, through the Office of the Vice President for Research at [Redacted].

I have read and understand this consent form.

(Participant Signature) ___________________________ (Date) __________

(Participant Printed Name) _____________________________

FSU Human Subjects Committee Approved on 2/01/11. Void after 1/31/12. HSC# 2010 5661
REFERENCES


BIOGRAPHICAL SKETCH

Andrea Sell

Andrea Sell completed her Bachelors degree in Psychology at The University of Florida in the spring of 2006. She enrolled in Florida State University’s Cognitive Psychology program in the summer of 2007. From there, she obtained her Master’s degree in the fall of 2009 under the advisement of Dr. Michael Kaschak, and began her doctoral program soon after. Andrea’s research interests include comprehension, language and spatial cognition.