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COGNITIVE FRAMING IN ACTION:

THE UPPER EFFECT IN BIMANUAL OBJECT MANIPULATION

A Thesis in

Psychology

by

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ABSTRACT

Cognitive framing effects have been widely reported in high-level decision-making. Here I report how the framing of instructions impacted a *physical* task. In the experiments to be described here, participants demonstrated a new perceptual-motor phenomenon during a bimanual rotation task. Participants moved a long PVC pipe from one height to another, always turning the pipe 180 degrees. The participants were given instructions verbally in some experiments and non-verbally (only visually) in others. In Experiment 1, I discovered the *upper effect*. The term refers to the fact that in the bimanual rotation task that I used, participants rotated the pipe to target positions in such a way that the end of the pipe end to which attention was drawn—what I call the "business" end—was moved through the upper workspace. A priori, it was possible for all the tasks I studied for participants to rely on a default strategy of always turning the pipe clockwise or always turning the pipe counter-clockwise. That is not what they did, however. In Experiment 2, I tested the hypothesis that the upper effect arose because participants sought to exploit gravity. I replicated the upper effect in a new apparatus. In Experiment 3, I tested to see the importance of explicit specifications found in the instructions on the upper effect. I was able to knock out the upper effect when no business end was mentioned. In Experiment 4, I addressed the question of whether the upper effect still held in the absence of verbal instructions. Participants showed the upper effect even more strongly. In Experiment 5, I checked whether the upper effect resulted from participants' wanting to avoid visual occlusion of the business end by their own arms. Again, participants performed the upper effect. I discuss how the findings from this series of studies shed light on the similarities between perceptual-motor planning and the high-level cognitive framing effects made famous by Kahneman and Tversky.

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Chapter 1

Introduction

For many years, the field of psychology paid little attention to the topic of motor control. The field invested considerable time into examining processes such as perception, memory, attention, and decision-making. These contributions aligned with the research aim of psychology, which is the study of mind and behavior. But why not study motor control? Motor control is the study of the control and coordination of muscles and neurophysiological processes involved in skilled performance. As it is defined, motor control appears to be a natural extension of the research goals of psychologists.

But this has not been the case, as motor control has been relatively understudied by psychologists (Rosenbaum, 2005). Traditional approaches to the study of human motor control have been captured in the works of physiologists and kinesiologists. What can psychologists add to the understanding of motor control that traditional approaches do not already provide? Here I present a series of experiments that demonstrate how cognitive processes can play a critical role in how actions are performed.

To explore this question, I will focus on bimanual object rotation tasks. Most of the published bimanual object rotation experiments have used two objects being rotated at once (Weigelt et al., 2006; Fischman et al., 2003; Hughes & Franz, 2008; Janssen et al., 2009). Consequently, little is known about how individuals plan and perform bimanual actions involving single (large) objects. In this thesis, I shed light on this surprisingly neglected topic. How, quite simply, do people use their two hands to move single, large objects? It turns out that the way they do—what I have discovered here—reflects a powerful cognitive framing effect that has not been previously reported. This framing effect speaks to the influence of semantic and perceptual constraints impacting movement.

Here I will discuss previous methods for examining cognition and object manipulation, in both unimanual and bimanual tasks. Then I will describe a series of tasks that required participants to rotate a pipe 180 degrees while presented with various semantic and perceptual constraints. I will next present the data collected from these studies. I will conclude with a discussion of the implications of my findings for the fields of motor control and psychology.

Co-manipulation

The planning of actions offers researchers insight in the translation of mental life into human behavior (Rosenbaum, 2010). From this body of literature has emerged an appreciation of several “soft” constraints for physical actions (see reviews, Rosenbaum et al., 2012, 2013, 2014). Such constraints are soft in the sense that they are optional or psychological, and not dictated by physics, including the biomechanics of the body.

The soft constraints to which I refer concern “co-manipulation,” the manual analog of co-articulation in speech. An example of speech co-articulation is rounding the lips before saying the t in tulip (Skoyles, 1998). Co-manipulation effects are analogous anticipatory effects in manual behavior (Rosenbaum et al., 2014). The research on anticipatory effects highlights the capability of humans to plan for what is coming next.

Rosenbaum and colleagues (1990) examined one example of co-manipulation in a laboratory setting where they asked participants to grasp and rotate dowels. Participants showed a strong preference to grasp the dowels in an uncomfortable grasp in order to achieve a comfortable final posture. Rosenbaum et al. (1990) called this the *end-state comfort* effect. Direct measures of comfort were obtained for this task. Participants rated the comfort of various postures on a scale of 1 to 5 (least to most comfortable). The ratings supported the notion that participants sought to maximize comfort at the ends of the dowel rotations (Rosenbaum et al., 1990).

Whereas the end-state comfort effect concerned how objects are grasped depending on what would be done with them, another constraint for action planning turned out to be where objects are grasped depending, again, on what would be done with them. Cohen and Rosenbaum (2004) provided evidence of such an effect in connection with their discovery of a grasp height effect. These authors found that individuals grasped the same object low if it was to be moved to higher locations or high if it was to be moved to lower locations. The grasp height effect reflected a desire for better comfort and control at the end of the object's vertical displacement, much as the end-state comfort effect reflected a desire for better comfort and control at the end of the object's rotation.

Bimanual Object Manipulation

The above-mentioned studies have been primarily concerned with the issue of how people manipulate objects with one hand. Co-manipulation has also been evaluated in bimanual object manipulation. These experiments have primarily employed tasks that, by definition, required two hands, though typically participants moved two objects rather than one (Weigelt et al., 2006; Fischman et al., 2003; Hughes & Franz, 2008; Janssen et al., 2009); that distinction will be important in the experiments discussed in this thesis. The previously published experiments revealed another soft constraint in action planning—a preference for movement symmetry (Hughes et al., 2011; Huhn et al., 2014; Janssen et al., 2009; Kelso et al., 1979; Kunde & Weigelt, 2005; Weigelt et al., 2006). This preference has been observed in bimanual object manipulation, where symmetry is associated with the desire to couple the arms spatiotemporally during the planning and execution phases of movement (Kelso et al. 1979; Kelso, 1984; Marteniuk et al.

1984; Serrien and Swinnen, 1997). The evaluation of bimanual symmetry in grasping objects include studies that have required participants to simultaneously move two unused plungers from start locations to target locations (van der Wel & Rosenbaum, 2010; Huhn et al., 2014).

As previously mentioned, most of the studies reviewed here required participants to move two objects, one in each hand. We know from our daily tasks, though, that many of the actions we perform with both hands only involve a single object. A key component of this thesis is to provide a better understanding of how the hands coordinate to achieve manipulation of a single object.

Conceptual Constraints

I have briefly discussed how object manipulation is governed by a hierarchy of soft constraints in unimanual and bimanual tasks. I now turn to other psychological processes involved in the selection of actions. A central theme of my thesis is the importance of higher-order constraints involved in motor planning. As suggested by one research team, “higher-order constraints may be able to override the spatio-temporal constraints that occur at the lower levels of the system” (Franz et al., 1991, p. 149). This suggestion followed a discussion of an experiment in which participants were asked to simultaneously draw a circle with one hand and a straight line with the other hand. The circles became more line-like and the lines became more circle-like, which demonstrated bimanual interference.

The bimanual interference just described is the result of spatio-temporal constraints (Franz et al., 1991). Despite the interference demonstrated in the circle and line task, we all know from everyday experiences that our hands are capable of working together to complete a multitude of activities. That being said, what higher-order constraints guide our hands in this coalition, helping us to avoid manual gridlock? An appreciation of such constraints will give us a better understanding, overall, of the motor system.

To explore how higher-order processes can impact the planning and execution of movements, Franz and McCormick (2010) had participants reach to a circular target with one hand or two. The authors adapted the language of the instructions presented to the participants. In the bimanual conditions, by varying the instructions to be presented with the words “both” or “and,” Franz and McCormick found that participants responded differently. In conditions where participants were told “both” hands, participants represented the task as a *single bimanual* movement. In tasks involving “and” in the instructions (e.g. left hand *and* right hand), participants represented the task as *two unimanual* movements. Importantly, the instructions caused participants to process the task as two separate tasks or as a joint, unified task. The authors referred to this semantic manipulation as a *conceptual unifying constraint*.

Did these findings only apply to semantic manipulations? Or do other manipulations reveal conceptual constraints? To address this question, Franz and McCormick (2010) explored how perceptual constraints could impact the same reaching task. They showed target circles either coupled with a line or decoupled with no line. Franz and McCormick (2010) used this visual-perceptual manipulation to see if participants engaged separate unimanual or joint bimanual strategies. The participants did so, consistent with the hypothesis that conceptual constraints play a key role in the planning and control of manipulation.

Cognitive Framing

The findings discussed above highlight the role of semantics and visual-perceptual factors in motor planning. They underscore the fact that when presented with the same task but with different semantic or perceptual manipulations, people’s actions differ. This finding echoes one that has been one of the most famous discoveries in psychology, the discovery of framing effects (Tversky & Kahneman, 1981).

Framing effects can be understood by considering the following instruction: “Check the box below if you want to participate in the organ donor program.” This was an instruction used in Denmark, The Netherlands, and the UK. In Austria, Belgium, and France a different instruction was given: “Check the box below if you want to opt out of the organ donor program.” Both instructions amounted, logically, to the same thing. Nevertheless, when people were asked to opt in or to opt out, the outcomes were dramatically different. In Denmark, The Netherlands, and the United Kingdom only 4%, 28%, and 17% of the drivers, respectively, chose to donate. This rate was starkly different from Austria’s 100%, Belgium’s 98%, and France’s 100% enrollment (Ariely, 2008).

Results like these dramatically demonstrate cognitive framing effects, where the way questions are framed affects the way participants answer the questions. Said another way, different wording of the questions result in different responses, despite the fact that if one were to compare the framed questions and answers side by side, they are logically identical.

The results of Franz and McCormick (2010) can be likened to the results of Ariely (2008) and Tversky and Kahneman (1981). In the organ donor task, the question, despite different wording, was ultimately seeking volunteers for the donor program. When Franz and McCormick (2010) asked participants to reach during different semantic and visual-perceptual manipulations, the task was always to simply reach and point to a target. The authors found that changes in instructions and visual representation of the circles (i.e., coupled or decoupled) resulted in different motor responses, similar to how Ariely (2008) described how a change in wording of the organ donor question resulted in different responses.

The similarity between the reaching task and the organ donor question provides an encouraging opportunity for exploring and bringing together two very different and important areas of psychology: high-level decision-making and motor control. Pursuing this issue points in turn to a fundamental question about cognitive framing that has received little attention (for review see Kühberger, 1998). What are the origins of cognitive framing effects? Asked another way, from what basic mechanisms did cognitive framing evolve?

In this thesis, I will not try to answer this question definitively, but I will offer data that may be taken to suggest that cognitive framing effects may have come from, or at least are expressed in, the control of physical action.

Preview of the Experiments

In the experiments to be described here, participants demonstrated a new perceptual-motor phenomenon during a bimanual rotation task. Participants moved a 5 foot long PVC pipe from one height to another, always turning the pipe 180 degrees. The participants were given instructions verbally in some experiments and non-verbally (only visually) in others. Five experiments will be reported. Each of them had 24 participants from the Penn State community. Participants' movements were recorded using webcams (front view, side view, back view, and aerial view), used for coding purposes.

Through the experiments, I discovered a new phenomenon, which I call the *upper effect*. The term refers to the fact that in the bimanual rotation task that I used, participants rotated the pipe to target positions in such a way that the end of the pipe end to which attention was drawn—what I call the "business" end—was moved through the upper workspace. A priori, and perhaps as an engineer or physicist might have expected, it was possible for all the tasks I studied for participants to rely on a default strategy of always turning the pipe clockwise or always turning the pipe counter-clockwise. That is not what they did, however.

I discuss how the upper effect is a manifestation of cognitive influences, both semantic and perceptual. My findings add to the growing body of literature showing that higher-order effects play an important role in the way physical actions are performed. I refer to these as conceptual guiding constraints. I suggest these guiding constraints play a critical role in action planning and control.

The thesis from here on will have three main sections. The first will concern experiments demonstrating *semantic* guiding constraints. The second will concern experiments demonstrating *perceptual* guiding constraints. The third will concern the relation of my findings to other research in cognitive psychology and motor control, including the relation of stimulus-response compatibility to action control. The last section of the final discussion will provide speculations on cognitive framing and action more generally.

Chapter 2

Semantic Guiding Constraints on Peg Apparatus

In the first experiment, I evaluated semantic guiding constraints in bimanual coordination. I asked, quite simply, how do instructions impact the way people move a single large object, a long PVC pipe? I gave participants instructions that indicated which end of the pipe was supposed to be brought to a specified target. Each pipe transport task required a vertical shift of the pipe and a 180 degree rotation. The choice to rotate the pipe either clockwise or counter clockwise was left to the discretion of the participant in every trial. Participants were not informed that, because both choices required a 180 degree rotation, either direction of rotation would yield the same resulting pipe orientation. Therefore, the requirements of every trial could be satisfied by the participant whether a clockwise or counter clockwise rotation was employed. The prediction was clear. If semantics acted as a guiding constraint for bimanual coordination, the rotation directions would depend on the specified instructions (e.g., clockwise rotations for certain instruction specifications and counter-clockwise rotations for other instruction specifications). Conversely, if semantics did not act as a guiding constraint of bimanual coordination, the rotation directions would not depend on the specified instructions. A given participant might always, or virtually always, turn the pipe clockwise or counterclockwise.

Experiment 1A -- Framing With 'Pipe-Target' (Original Order) Instructions

Method

Participants

Two independent groups of twenty-four participants volunteered for Experiment 1A and Experiment 1B. Participants were members of the Pennsylvania State University community. Experiment 1A participants were recruited during the summer of 2013 and were graduate students and staff in the cognitive area of the psychology department. All participants were naïve to the purpose and theoretical questions of the study. The age of the participants ranged from 20 to 60 (M = 29.30). Participants completed a short form of the Edinburgh handedness inventory (Oldfield, 1971). Twenty-three participants reported being right-handed and one reported being left-handed. None of the participants reported any neurological deficits.

Experiment 1B participants took part in the study in exchange for course credit. Participants ranged in age from 18 to 23 (M = 19.67). Participants completed a short form of the Edinburgh handedness inventory (Oldfield, 1971). Twenty-three reported being right-handed and one reported being left-handed. None reported any neurological deficits.

Design of Apparatus

Experiment 1A and 1B used the same apparatus (Figure 1), which consisted of wooden racks, each with three protruding wooden pegs, attached to either side of a 2.13 m tall by 0.92 m wide doorframe within the lab. Each wooden rack was 1.84 m long x 0.12 m wide x 14 cm deep. One rack was vertically fixed to the left trim of the doorframe. An additional rack was vertically fixed in the identical orientation to the right trim of the doorframe. The distance between the vertical rack and the right vertical rack was 0.85 m.

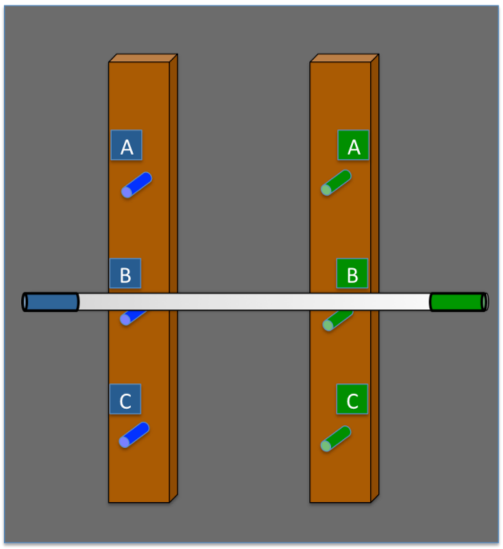

Figure 2. Peg apparatus. The pipe is on the pegs at 1.34 m.

The left and right racks were symmetrically mounted, beginning at 0.34 m above the floor and spanning a total of 1.83 m to a height of 2.17 m from the floor. Pegs protruded from the wooden racks. Each was 7 cm long with a 1 cm diameter. Vertically, the six pegs from the racks on the left and right side of the doorway were spaced 0.10 m away from one another. Horizontally, pegs on the left were distanced 0.96 m from pegs on the right.

Of the six pegs on the apparatus, three target pegs on the left board were marked with blue colored duct tape. These three marked target pegs constituted positions “blue A,” “blue B,” and “blue C.” On the right side, the horizontally symmetrical counterparts of the blue marked target pegs were labeled with green tape. These three positions were labeled “green A,” “green B,” and “green C.” Lateral positions “blue A” and “green A” were located 1.80 m above the floor, “blue B” and “green B” were located 1.34 m above the floor, and “blue C” and “green C” were located 0.88 m above the floor.

A single PVC pipe, 1.52 m in length and 0.02 m in diameter, rested horizontally across the left and right marked target pegs at either lateral position “A,” “B,” or “C.” One end of the pipe was marked with a strip of 0.05 m green duct tape and the other was marked with a 0.05 strip of blue duct tape. The pipe weighed 491 grams.

Procedure

At the start of each trial, the PVC pipe was positioned at one of the three heights (e.g. 1.80 m, 1.34 m, or 0.88 m). In each trial, the participant’s task was to listen to a specification read aloud by the experimenter and then, using the grasp orientation(s) of his or her choice, to move the designated end of the pipe to the designated target.

The specifications read aloud to participants included the colored end of the pipe to be rotated to one of the colored target gaps at position A, B or C, and then the destination target gap for this end of the pipe. For example, before a trial, the participant heard, “blue end, green A.” This instruction meant that s/he was to reach out, withdraw the pipe from its current position and rotate the pipe so that the blue end was brought to the green target peg at position A. Once the PVC pipe rested horizontally across both pegs at the designated target height with the stated end on the stated target peg, the trial ended and the participant returned his or her hands to his or her sides to await the next instruction.

All of the 24 participants in this experiment and the next one reported (48 participants in all) experienced 24 trials (2 possible pipe orientations at each starting position x 2 possible orientations at each target position x 3 target heights x 2 color specifications) arranged in a Latin square design. Trials were arranged in pseudo-random order so that the ending position of the pipe in each trial was the starting position for the following trial. As in all of the experiments, the starting position of the pipe was balanced over subjects. The pipe was always raised or lowered as well as rotated. The pipe's start position in any given trial was the position to which it was brought at the end of the previous trial. In cases when the pipe was brought to an incorrect position, the experimenter repositioned the pipe at that trial's start orientation. The participant then recompleted the trial. This happened infrequently. When all 24 trials were complete, the participant was debriefed.

Results

Data Analysis

Three webcams (Logitech QuickCam Ultra Vision, Model Number: V-UBH44) captured the movements of each participant on a computer. One webcam was placed to look at the front of the participant, a second webcam was place to look at the side of the participant, and a third webcam was place to look at the back of the participant. The webcams recorded participant's movement execution during each trial. Importantly, the webcams recorded the direction of rotation for each participant during each trial. Using a video-analysis program called Avidemux (http://fixounet.free.fr/avidemux/), my research assistants and I were able to view the video records frame-by-frame. We coded for actions of interest, in particular the direction of rotation. I then analyzed these data in Matlab (r2014b), where I obtained the means of the rotation strategies (e.g., clockwise or counter-clockwise) for the various conditions. Finally, I subjected these means to statistical analyses. I used this data analysis process for all of the experiments presented in this thesis.

Factors Affecting Rotation Direction

To determine whether participants had a particular preference for clockwise or counterclockwise rotation given a specified target direction or target height (Figure 2), I subjected the mean frequencies of clockwise rotations for each participant to a repeated-measures ANOVA whose design was 2 (target direction, left side or right side) x 3 (target height, 1.80 m or 1.34 m or 0.88 m). The ANOVA revealed a significant effect of target direction, $F(1,23) = 51.22$, $p < .001$. Pairwise comparisons showed that there was a statistically significant difference for clockwise preference when the target was on the right ($M = .84$) compared to when the target was on the left ($M = .24$), $p < .001$. The results revealed no other significant main effect or interactions, $p > .05$.

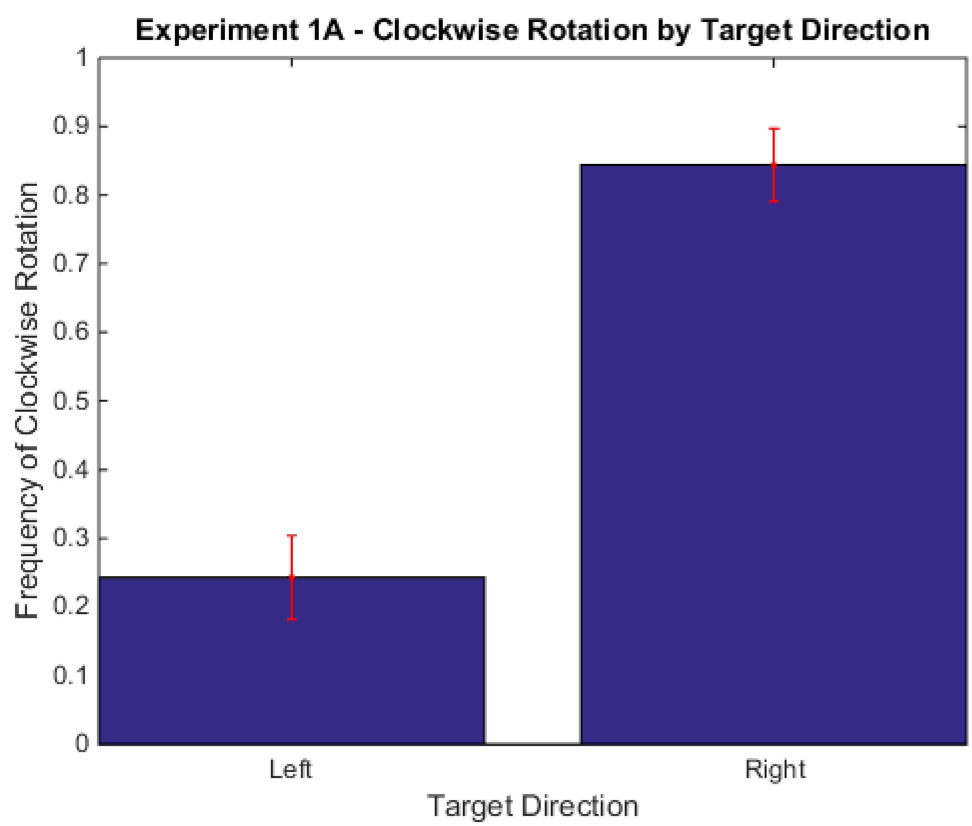

Figure 2. Frequencies of clockwise rotations for left and right targets in Experiment 1A. The error bars represent ±1 SE.

In connection with the ANOVA design just reported, note that the design was functionally equivalent to looking at start direction x start height or, for that matter, start direction x target height or target direction x start height. In other words, start direction and target direction were perfectly confounded. In addition, there was no way to statistically isolate the effects of start and target heights. I was aware of this going into the experiment but chose not to “worry” about this because of the vast amount of evidence indicating that target positions matter much more than start positions do in the way objects are grasped when they are moved to target destinations. For a review of the relevant studies, see Rosenbaum et al. (2012). This same design consideration applies to all the experiments reported here.

The results of the present experiment demonstrate that when participants were told to bring a specified pipe end (the “business end” of the pipe) to a target on the *right*, they preferred clockwise rotations, but when participants were told to bring the business end of the pipe to a target on the *left*, they preferred counter-clockwise rotations. Another way of saying this is that participants tended to bring the business end of the pipe through the upper part of the workspace. This tendency comprises the main empirical discovery of this thesis. I call this phenomenon the *upper effect*.

Factors Affecting the Upper Effect

To better understand the upper effect, I conducted another ANOVA that was, strictly speaking, equivalent to the ANOVA I just reported. The only difference was that, whereas the ANOVA just reported took as the dependent variable the frequency of clockwise rotations, the next ANOVA took as the dependent variable the frequency of rotations of the business end through the upper part of the workspace (i.e., above rather than below the axis of the rotation of the pipe, regardless of the height of the axis of rotation, which rose or fall depending on the height difference between the start and target positions). I asked, in other words, about the upper effect itself. How did it depend on the target orientation and height of target? I subjected the mean likelihoods of the ‘upper’ rotations per participant to a repeated-measures ANOVA whose design was 2 (target pipe orientation, blue on left and green on right or green on left and blue on right) x 3 (target height, 1.80 m or 1.34 m or 0.88 m). The ANOVA revealed no significant main effects or interactions, $p > .05$. However, the effect of target height approached significance, $F(1.394, 32.053) = 3.668$, $p = .051$ (Figure 3). When the pipe was brought to 1.80 m, there was a higher frequency of the upper effect ($M = 0.85$) compared to moving to 1.34 m ($M = 0.77$) and 0.88 m ($M = .78$). Mauchly’s test indicated that the assumption of sphericity was violated. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. These points aside, however, the most important result was that the frequency of the upper effect was always vastly different from chance.

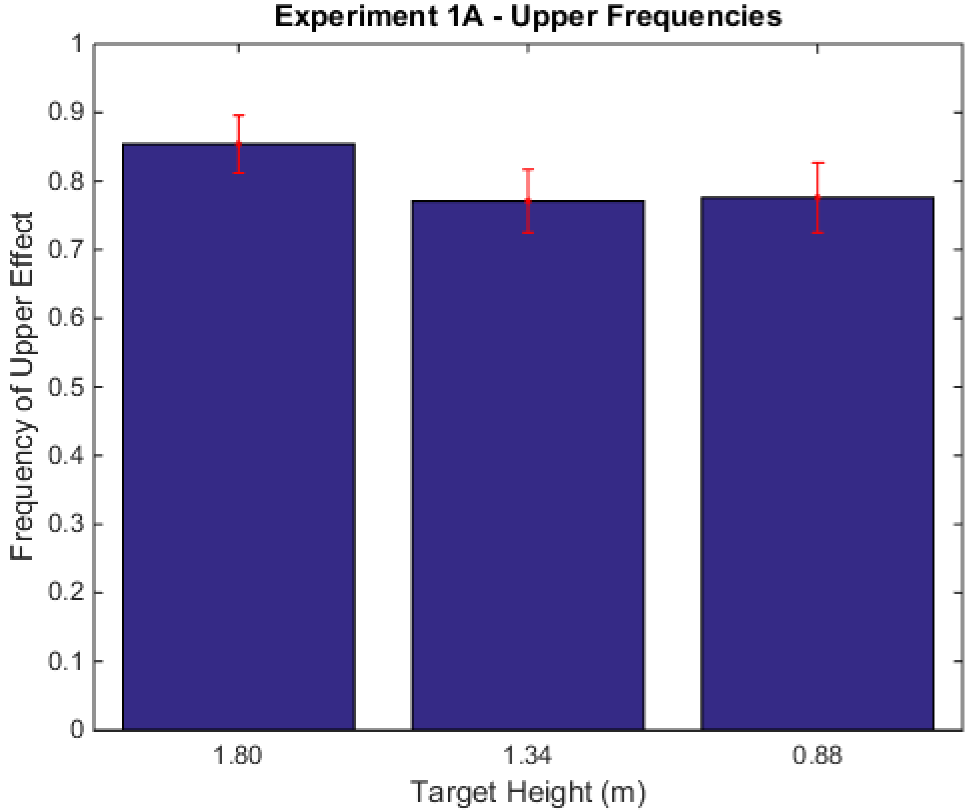

Figure 3. Frequency of upper effect at different heights in Experiment 1A. The error bars represent ±1 SE.

Discussion of Experiment 1A

The most important finding in this experiment was that there was a strong preference to bring the business end of the pipe through the upper workspace. As seen in Figure 3, the mean frequency of the upper effect vastly exceeded .5. If participants brought the business end of the pipe to a left target, they turned the pipe counter-clockwise, but if participants brought the business end of the pipe to a right target, they turned the pipe clockwise. *A priori*, subjects could have always turned the pipe clockwise or counterclockwise, but they did not.

Experiment 1B – Framing With Reversed Instructions

The upper effect would seem to be a cognitive effect. If it is, it might be affected by the wording of the instructions. In Experiment 1B, I addressed this question by reversing the order of the key terms for each task. If the upper effect is related to participants' mental representation of the task, then re-ordering the key terms in the instructions could influence the effect. On the other hand, if the upper effect is related to some other aspect of performance—some biomechanical factor, for example—the upper effect should not be affected by the instructions.

Method

Apparatus

Experiment 1B used the same apparatus as in Experiment 1A.

Procedure

The same procedure as Experiment 1A was used. The only variation was in the presentation of the instructions. The instructions were reversed relative to what they were in Experiment 1A. In Experiment 1A, participants first heard a specified colored pipe end followed by a specified target peg, as in "blue end, green A." In Experiment 1B, participants heard a specified target peg followed by the specified colored pipe end, as in "green A gets blue end." If the upper effect was cognitive, the ordering of the terms could affect the likelihood of the upper effect. Conversely, if the upper was not cognitive, the ordering of the terms would be expected to have no influence.

Results

Factors Affecting Direction of Rotation

To determine whether participants had a particular preference for clockwise or counterclockwise rotation as a result of specified target direction or target height (Figure 4), I subjected the means of clockwise rotations for each participant to a repeated-measures ANOVA whose design was 2 (target direction, left side or right side) x 3 (target height, 1.80 m or 1.34 m or 0.88 m). The ANOVA revealed a significant effect of target direction, $F(1,23) = 15.698$, $p < .01$. Pairwise comparisons indicated that there was a statistically significant difference for clockwise preference when the target was on the right ($M = .80$) compared to when the target was on the left ($M = .53$), $p < .01$.

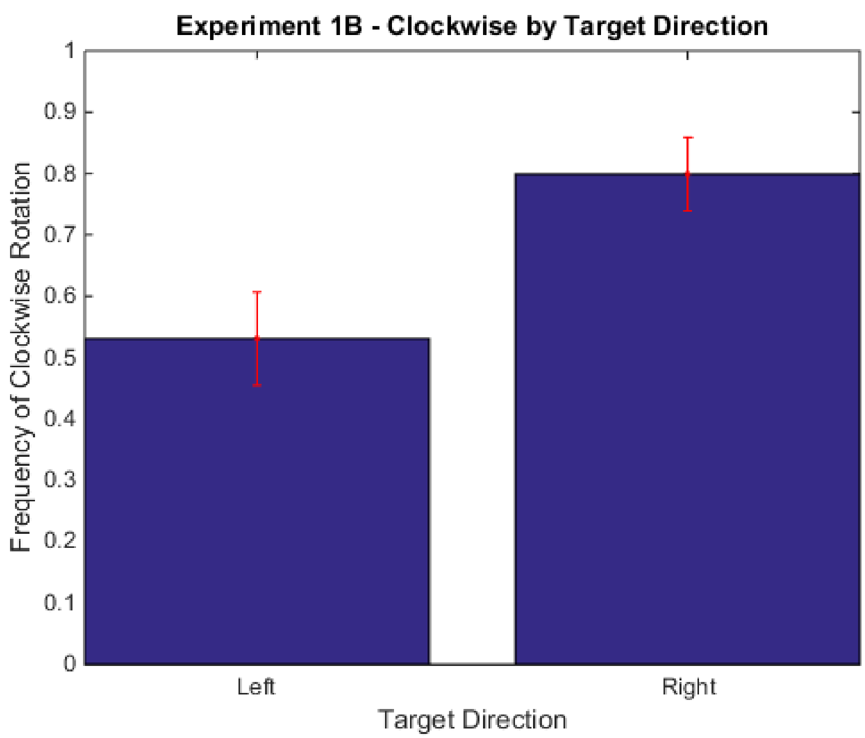

Figure 4. Frequencies of clockwise rotations for left and right targets in Experiment 1B. The error bars represent ±1 SE.

The ANOVA also revealed a significant two-way interaction between target direction and target height F(1,23) = 9.471, $p < .01$ (Figure 5). There was no other significant main effect or interaction, $p > .05$. When the participants were instructed to move the pipe to a target on the right, there was a strong preference for clockwise rotations. As shown in Figure 5, this changed with target height. When the business end of the pipe had to go the highest left target, there was a weaker preference for clockwise rotations than for lower targets, but the preference for clockwise rotations increased as the heights of the rights decreased. Meanwhile, the frequency of clockwise rotations did not depend on target height for right-side targets.

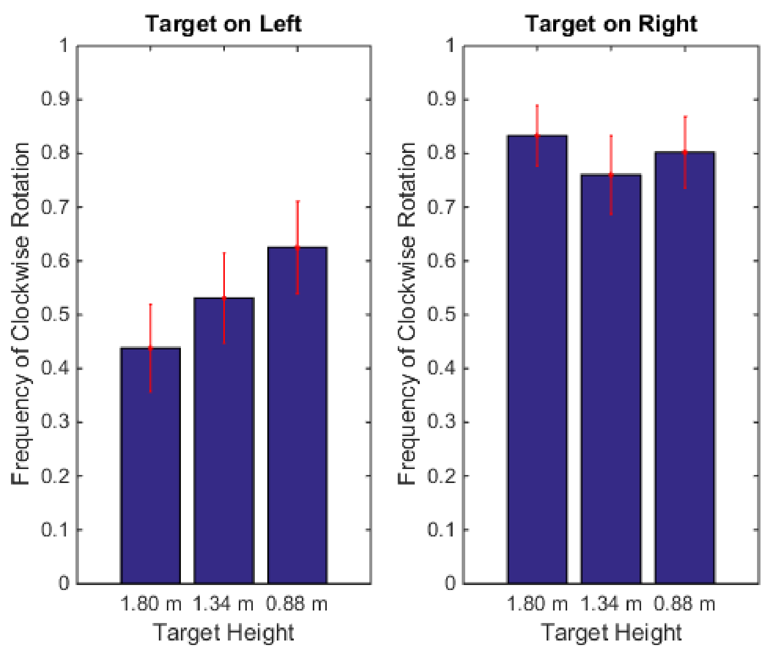

Figure 5. Frequencies of clockwise rotations for left and right targets at different heights in Experiment 1B. The error bars represent ±1 SE.

Factors Influencing the Upper Effect

As for Experiment 1A, I also analyzed the data in terms of the upper effect (Figure 6). I subjected the mean likelihoods of the upper rotations to a repeated-measures ANOVA whose design was 2 (target pipe orientation, blue on left and green on right or green on left and blue on right) x 3 (target height, 1.80 m or 1.34 m or 0.88 m). The ANOVA revealed a significant effect of target height, $F(2, 46) = 5.992$, $p = .005$. The frequency of participants performing the upper effect increased as the target height increased: 0.88 m ($M = .59$), 1.34 m ($M = .63$), and 1.80 m ($M = .70$). Pairwise comparisons with Bonferroni correction revealed that target heights 1.80 m and 0.88 m were significantly different, $p = .007$, though the target height of 1.34 m was not significantly different from the other target heights, $p > .05$. Mauchly's test indicated that the assumption of sphericity was not violated. The results revealed no other significant main effect or interactions, $p > .05$.

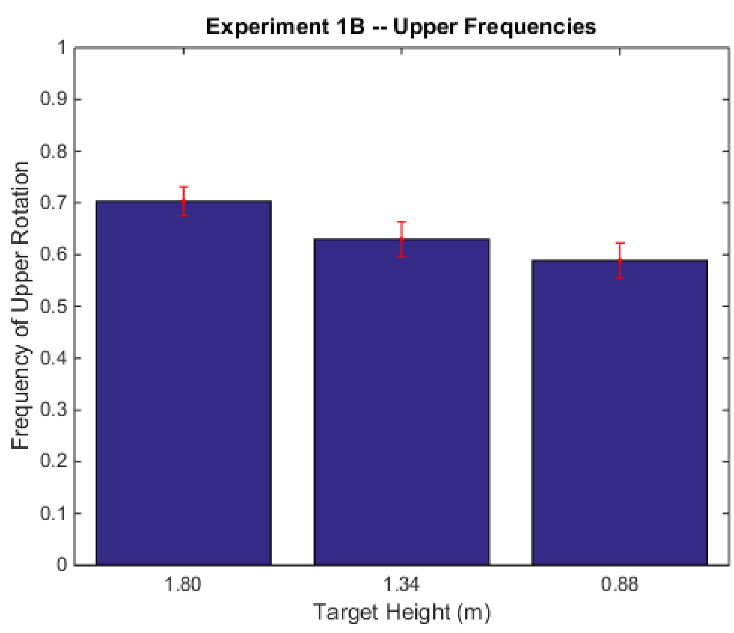

Figure 6. Frequencies of upper effect at different heights in Experiment 1B. The error bars represent ±1 SE.

Participants again brought the business end of the pipe (i.e., the specified target end) through the upper workspace. As before, though subjects could have always turned the pipe clockwise or counterclockwise, they did not. Rather, they changed the direction of rotation according to which end of the pipe would go to which side target.

I also tested the upper effect's sensitivity to the ordering of instructions (Figure 7), by performing a repeated measures ANOVA whose design was 2 (target pipe orientation, blue on left and green on right or green on left and blue on right) x 3 (target height, 1.80 m or 1.34 m or 0.88 m) x 2 (instructions, original or reversed). There was a main effect of instructions $F(1, 46) = 8.707$, $p = .005$. Pairwise comparisons revealed participants who received the original instructions showed the upper effect more strongly ($M = .80$) than did participants who got the reversed instructions ($M = .64$), $p = .005$.

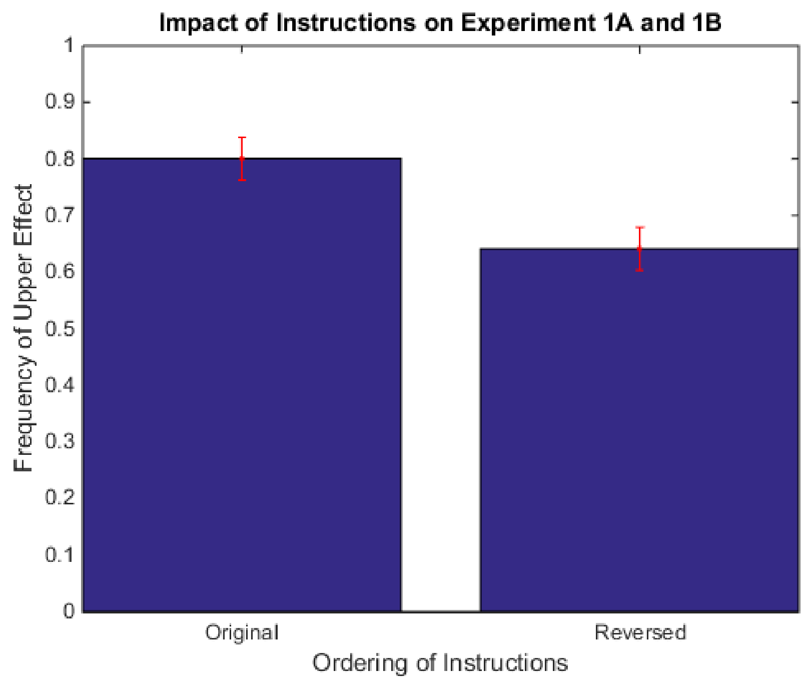

Figure 7. Frequencies of upper effect for ordering of instructions in Experiments 1A and 1B. The error bars represent ±1 SE.

The ANOVA also revealed a main effect of target height $F(2, 92) = 9.070$, $p < .001$. Pairwise comparisons with Bonferroni correction revealed that target height (Figure 8) 1.80 m ($M = .78$) was significantly different from 1.34 m ($M = .70$) and 0.88 m ($M = .68$), $p < .005$. There was no difference between target heights 1.34 m and 0.88 m, $p > .05$.

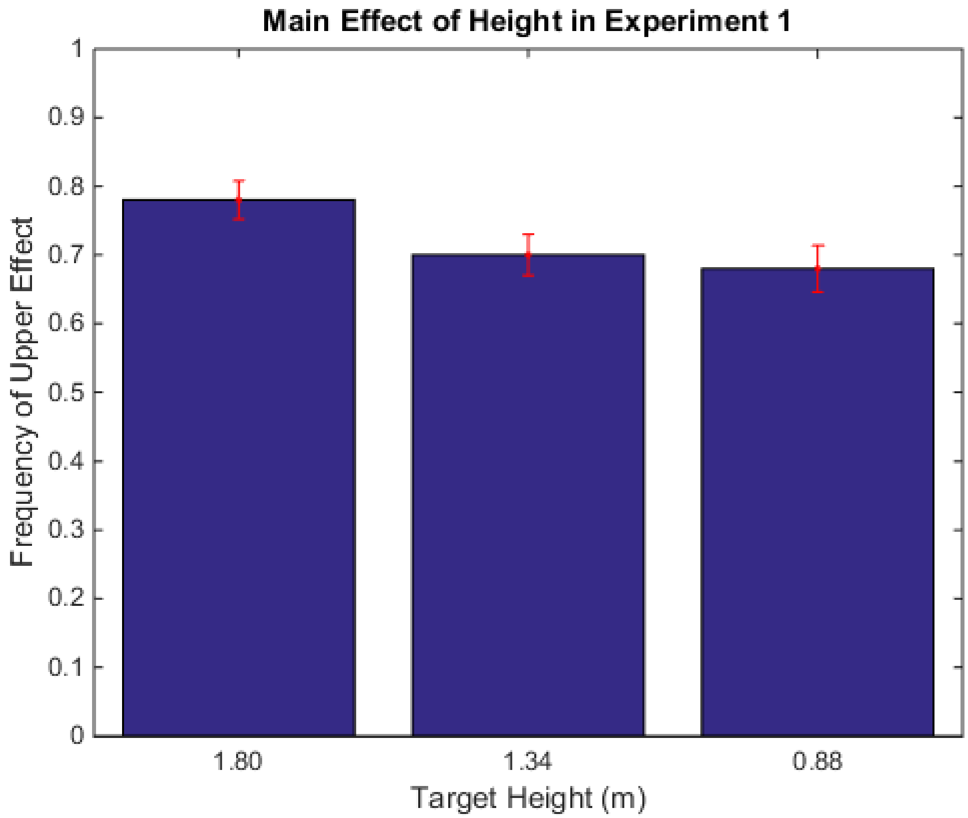

Figure 8. Frequencies of upper effect at different heights in Experiment 1. The error bars represent ±1 SE.

Discussion of Experiment 1

In Experiment 1A, I discovered the upper effect, the tendency to move the business end of the pipe through the upper part of the workspace. *A priori*, participants could have always turned the pipe clockwise or counterclockwise, but they did not. Instead, they brought the business end through the upper hemisphere. In Experiment 1A, the instructions took the form where the business end was specified first followed by the target specification (e.g., “blue end, green A). In Experiment 1B, I sought to better understand the basis of this effect by changing the ordering of the terms in the instructions, so they took the form where the target location was first stated, followed by the specified pipe end (e.g., “Green A gets blue end). I found that participants still demonstrated the upper effect, but not as strongly as in Experiment 1A.

These results show the robustness of the upper effect, which appeared in both experiments. The change of magnitude of the effect, which might have been due to differences in the participant sample or other extraneous factors, was nonetheless consistent with the hypothesis that the effect has a cognitive basis. Similar to reports of cognitive framing effects in high-level decision- making, participants moved somewhat differently based on the wording of the instructions.

Chapter 3

Semantic Guiding Constraints on Gap Apparatus

In Experiment 1, I discovered the upper effect, the tendency to move the business end of the pipe through the upper part of the workspace. In Experiments 1A and 1B, I changed the ordering of the terms in the instructions and found that participants still demonstrated the effect, though the strength of the upper effect was affected by the wording change (or some other extraneous factor caused that change).

I suggested that the upper effect was a cognitive effect, but another non-cognitive possibility remains. As a potential byproduct of the peg apparatus used in Experiment 1, it could be that the upper effect resulted from participants exploiting gravity. Participants might have brought the pipe to a height from which they could drop the business end onto its target peg. This would not necessarily be cognitively uninteresting because the ability to reason about the mechanical affordances of objects, including the possibility of simply dropping one end of a pipe, is not trivial. Still, I wanted to know whether this fact alone might have accounted for the upper effect.

To address this concern, I modified the apparatus so it did not allow participants to drop the pipe onto the targets. Where there were pegs in Experiments 1A and 1B, there were gaps in Experiments 2A and 2B.

Experiment 2A -- Framing With Original Instructions

Method

Participants

I tested two independent groups of twenty-four participants for Experiment 2A and Experiment 2B. Participants were members of the Pennsylvania State University community and participated in exchange for course credit. The age of the participants ranged from 18 to 23 (M = 19.79) in Experiment 2A and from 18 to 25 (M = 19.74) in Experiment 2B. Participants completed a short form of the Edinburgh handedness inventory (Oldfield, 1971). Twenty-three participants in Experiment 2A and twenty-four participants in Experiment 2B reported being right-handed. One participant reported being left-handed in Experiment 2A. None of the participants reported any neurological deficits.

In Experiment 2A, I used the same procedure as in Experiment 1A except with panels that had gaps instead of pegs.

Design of Apparatus

As seen in (Figure 9) I attached boards to the door frame so gaps between the boards were where the pegs had been. Each gap was 3.2 cm wide. The left and right topmost board was 0.39 m long, the four middle boards were 0.43 m long, and the left and right bottommost boards were 0.55 m long. The left boards were 0.82 m from the right boards. The gaps were marked in a similar fashion as the pegs, marked as either “A,” “B,” or “C.” As in Experiment 1A and 1B, these letters corresponded to the respective distances from the floor: 1.80 m, 1.34 m, and 0.88 m. Participants used the same PVC pipe, with the marked blue and green ends.

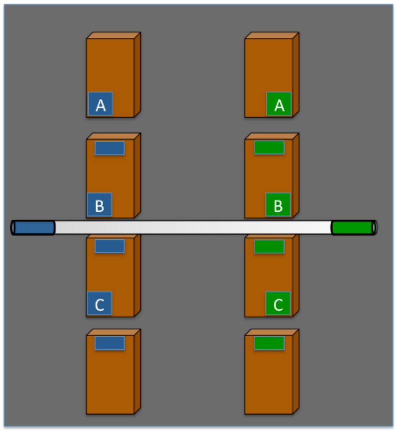

Figure 9. Gap apparatus. The pipe is in the gap, resting on top of the boards with C on their bottoms.

Procedure

Participants followed a similar procedure to Experiment 1A. In each trial, they listened to an instruction from the experimenter such as "green end, blue C." Then they used the grasp orientation(s) of his or her choice (grasp orientations could, and often did, change during the participant's movement in any given trial), rotated the PVC pipe 180 degrees either clockwise or counter clockwise into the named position. As in the previous study, the pipe was always raised or lowered as well as rotated. The pipe was never kept at the same height where it started.

The specifications read aloud to participants included the colored end of the pipe to be rotated to one of the colored target gaps at position A, B or C, and then the destination target gap for this end of the pipe. For example, participants heard the specification, "blue end, green A." This meant that s/he reached out, withdrew the pipe from its current position and, using one or both hands, rotated the pipe so that the blue end was located at the green target gap at position A. When the PVC pipe was successfully inserted horizontally across both gaps at the designated target height, with the stated end in the stated gap and the unstated end in the unstated gap, the trial ended and the participant was asked to return his or her hands to his or her sides to await the next instruction. In cases when the pipe was brought to an incorrect position, the experimenter repositioned the pipe at that trial's start orientation. The participant then recompleted the trial. This happened infrequently.

All of the 24 participants per experiment (48 participants in all) experienced 24 trials (2 possible pipe orientations at each starting position x 2 possible orientations at each target position x 3 target heights x 2 color specifications) arranged in a Latin square design. Trials were arranged in pseudo-random order so that the ending position of the pipe in each trial was the starting position for the following trial. When all 24 trials were complete, the participant was debriefed and dismissed.

Results

Factors Affecting Rotation Direction

To determine whether participants had a preference for clockwise or counterclockwise rotation (Figure 10) given a specified target direction or target height, I subjected the mean frequencies of clockwise rotations for each participant to a repeated-measures ANOVA whose design was 2 (target direction, left side or right side) x 3 (target height, 1.80 m or 1.34 m or 0.88 m).

The ANOVA revealed a significant effect of target direction, $F(1,23) = 19.426$, $p < .001$. Pairwise comparisons showed that there was a statistically significant difference for clockwise preference when the target was on the right ($M = .72$) compared to when the target was on the left ($M = .25$), $p < .001$. There was no other significant main effect or interaction, $p > .05$.

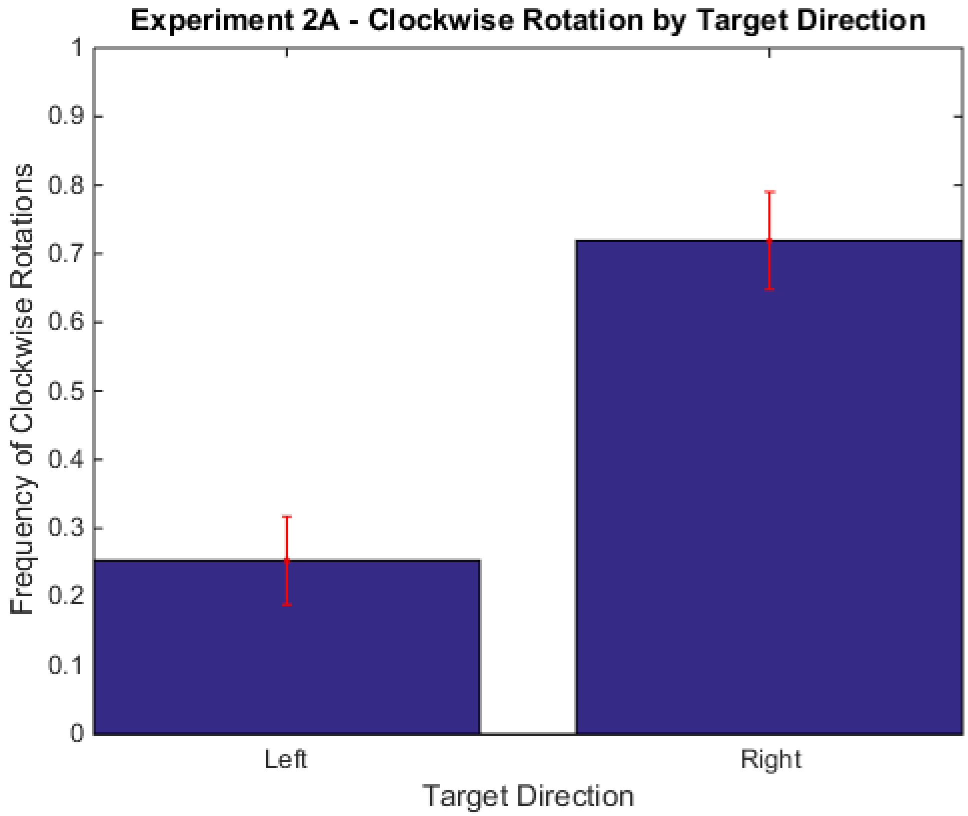

Figure 10. Frequencies of clockwise rotations for left and right targets in Experiment 2A. The error bars represent ±1 SE.

Factors Affecting the Upper Effect

I also analyzed the data in terms of the upper effect. I subjected the mean likelihoods of the upper rotations to a repeated-measures ANOVA whose design was 2 (target pipe orientation, blue on left and green on right or green on left and blue on right) x 3 (target height, 1.80 m or 1.34 m or 0.88 m). The ANOVA revealed a significant effect of target height $F(2, 46) = 4.339$, $p = .019$. There was a quadratic relationship between the target height and the upper preference. The upper strategy varied as a quadratic relationship (Figure 11) between targets heights 1.80 m ($M = .80$), 1.34 m ($M = .70$) and 0.88 m ($M = .77$). Pairwise comparisons with a Bonferroni correction revealed a statistically significant difference for the upper effect when the target height was 1.80 m and 1.34 m, $p < .05$. Mauchly's test for the assumption of sphericity were not violated. There was no other significant main effect or interaction, $p > .05$.

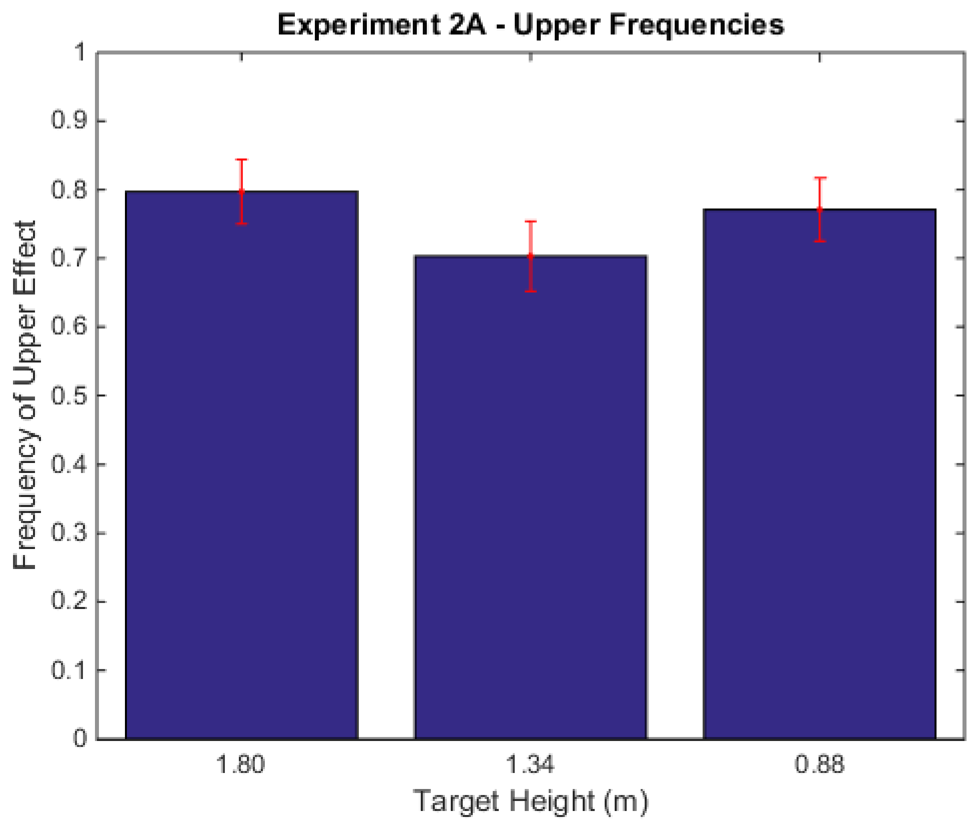

Figure 11. Frequencies of upper effect at different heights in Experiment 2A. The error bars represent ±1 SE.

Discussion of Experiment 2A's results

Participants using the gap apparatus demonstrated the upper effect. Instructions to rotate the pipe to a right side target resulted in clockwise rotations and instructions to rotate to a left side target resulted in counter clockwise rotations. As in Experiment 1, given the explicit instruction-specified constraint (e.g., green end, blue A), participants added their own implicit constraint onto the rotation task.

Experiment 2B – Framing With Reversed Instructions

I was encouraged by the replication of Experiment 1A's findings in Experiment 2A. It demonstrated that the upper effect was not a byproduct of the pegs, as it was still present in the gap apparatus. Therefore, the upper effect was not simply due to dropping the pipe.

In Experiment 2B, I determined I wanted to attempt to replicate the findings of Experiment 1B in the gap apparatus. In Experiment 1B, I was interested in how the upper effect was impacted by the ordering of the key terms in the instructions (e.g. naming the colored end of the pipe followed by the target location to receive the pipe). I addressed that question by reversing the order of the key terms for each task. I resolved in Experiment 2A that the upper effect was not simply due to dropping the pipe onto the pegs. I now questioned whether the potential sensitivity of the upper effect noted in Experiment 1B would also be replicated.

Method

Design of Apparatus

Experiment 2B used the same apparatus that was used in Experiment 2A.

Procedure

The procedure of Experiment 2B was the same as Experiment 2A. The only variation was in the presentation of the instructions. The specifications read aloud to participants included the destination target gap, followed by the colored end of the pipe to be rotated. The word "gets" was added between the two specified pieces of information. For example, before a trial, the participant heard the specification, “green A gets blue end.” The participants then followed the same procedures as in Experiment 2A.

Results

Factors Affecting Rotation Direction

To determine whether participants had a preference for clockwise or counterclockwise rotation as a result of specified target direction or target height, I subjected the mean frequencies of clockwise rotations for each participant to a repeated-measures ANOVA whose design was 2 (target direction, left side or right side) x 3 (target height, 1.80 m or 1.34 m or 0.88 m).

The ANOVA revealed a significant effect of target direction, $F(1,23) = 20.189$, $p < .001$. Pairwise comparisons showed that there was a statistically significant difference for clockwise preference when the target was on the right ($M = .67$) compared to when the target was on the left ($M = .36$), $p < .001$ (Figure 12). There was no other significant main effect or interaction, $p > .05$.

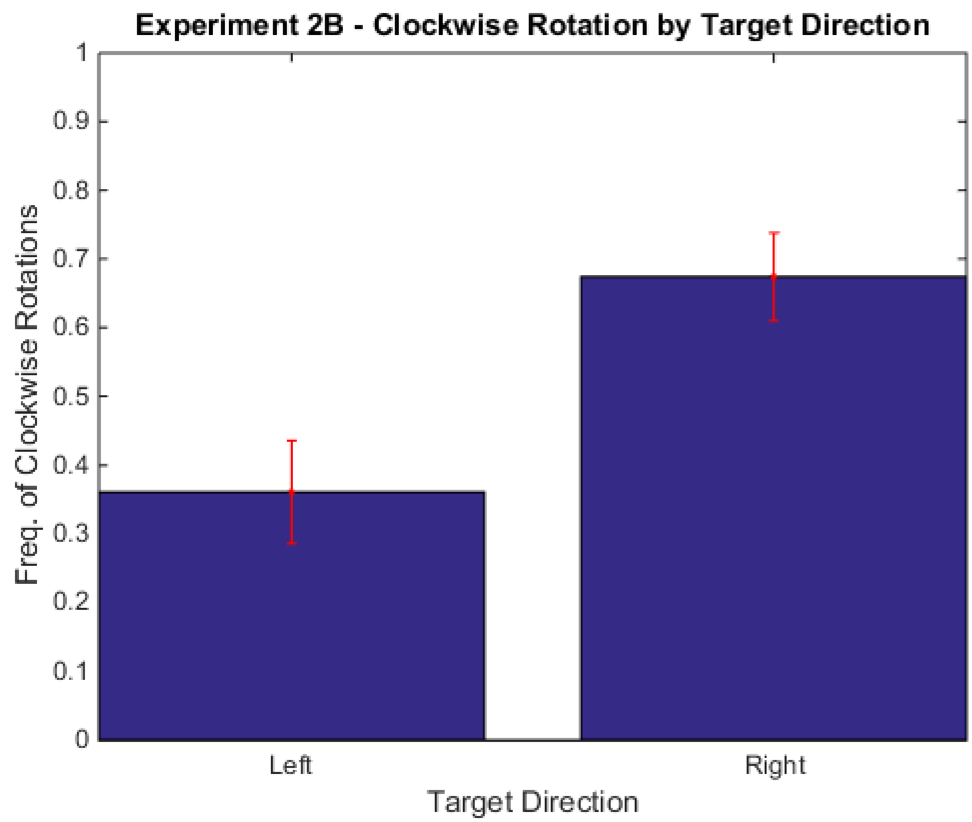

Figure 12. Frequencies of clockwise rotations for left and right targets in Experiment 2B. The error bars represent ±1 SE.

Factors Affecting the Upper Effect

To better understand the upper effect, I asked whether it depended on the target orientation and the height of target. I subjected the mean likelihoods of the ‘upper’ rotations per participant to a repeated-measures ANOVA whose design was 2 (target pipe orientation, blue on left and green on right or green on left and blue on right) x 3 (target height, 1.80 m or 1.34 m or 0.88 m).

The ANOVA revealed a main effect of target orientation F(1, 23) = 5.412, p = .029 (Figure 13). The upper effect was more frequent when the target positioning of the pipe had the blue end on the left and the green end on the right (M = .70) compared to when the green end was on the left and the blue end was on the right (*M* = .65). Pairwise comparisons with a Bonferroni correction revealed that these two were significantly different, $p = .029$. The results revealed no other significant main effect or interactions, $p > .05$.

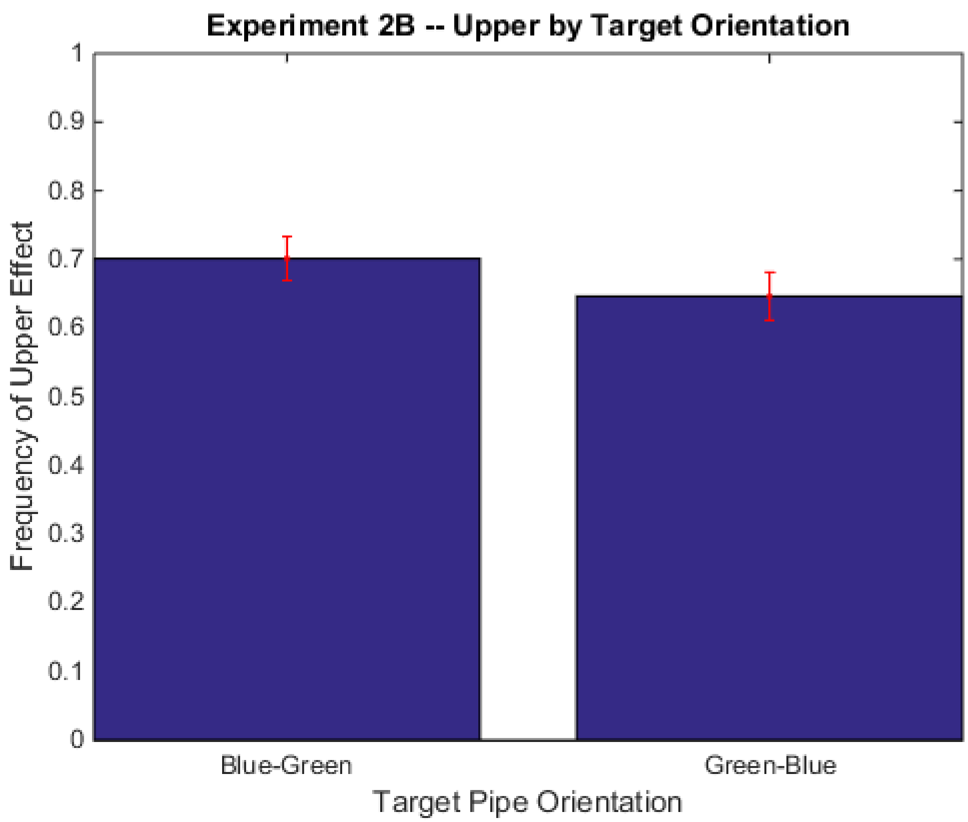

Figure 13. Frequencies of upper effect at different target pipe orientations in Experiment 2B. The error bars represent ±1 SE.

Participants again brought the business end of the pipe through the upper workspace. The results remained above chance. As before, participants could have always turned the pipe clockwise or counterclockwise. Instead, they showed a preference for the upper effect, adjusting their rotation according to target specification.

Differences in upper effect due to reversal of instructions

In Experiment 2B, I aimed to better understand how the ordering of the key terms in the instructions (i.e. the original 'pipe-target' or reversed 'target-pipe') impacted the upper effect, similar to the analysis I performed in Experiment 1B. To test the upper effect's sensitivity to the semantic manipulation of the ordering of the instructions (Figure 14), I performed a repeated measures ANOVA whose design was 2 (target pipe orientation, blue on left and green on right or green on left and blue on right) x 3 (target height, 1.80 m or 1.34 m or 0.88 m) x 2 (instructions, original or reversed). There was no other significant main effect or interaction, $p > .05$. Unlike Experiment 1B where I found that the ordering of instruction was significantly different, I did not find the same level of sensitivity in Experiment 2B.

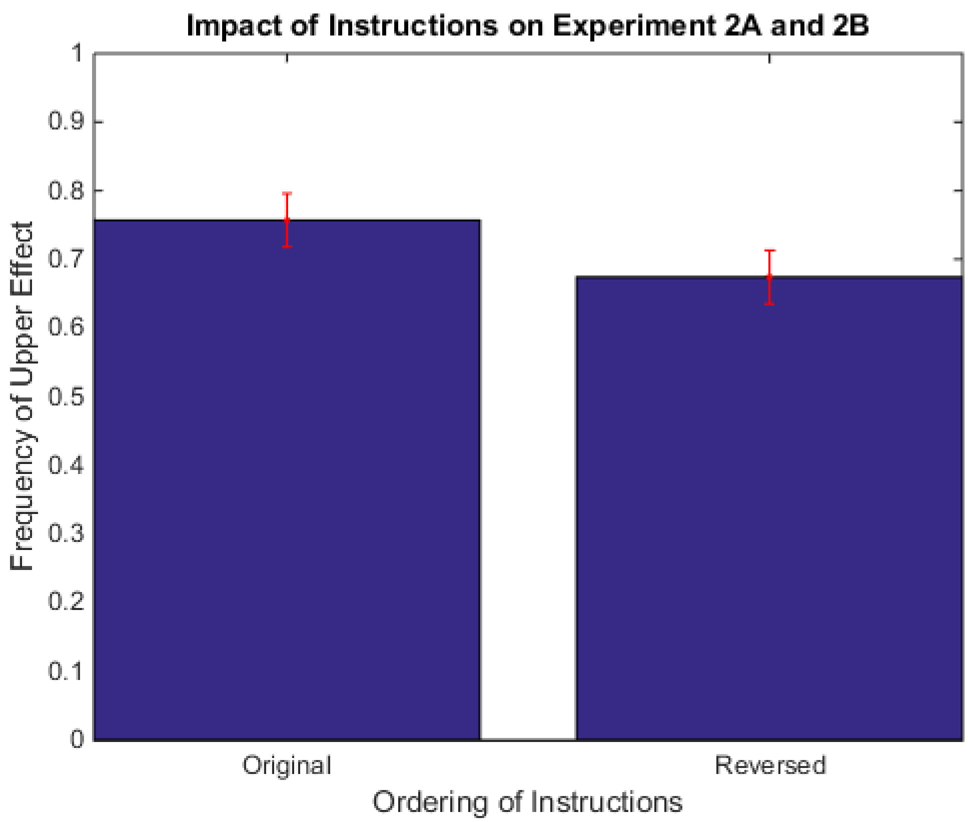

Figure 14. Frequencies of upper effect for ordering of instructions in Experiments 2A and 2B. The error bars represent ±1 SE.

Discussion of Experiment 2

In Experiment 2, I replicated my finding of the upper effect. By modifying the apparatus with gaps, I provided evidence that the upper effect is not just due to simply dropping the pipe onto pegs. Participants could have always turned the pipe clockwise or counterclockwise, but they did not. They brought the business end of the pipe through the upper hemisphere. In Experiment 2A, I changed the ordering of the terms in the instructions and found that participants still demonstrated the upper effect. As in Experiment 1B compared to Experiment 1A, the upper effect was somewhat weaker when the target was named before the business end. Finding this same attenuation with the peg apparatus (Experiments 1A and 1B) and with the gap apparatus (Experiments 2A and 2B) suggests that it was not just due to the subjects in the two groups participating in Experiments 1A and 1B, nor to some other extraneous factor.

Chapter 4

Semantically-Stripped Instructions

In the previous experiments, I found that the upper effect held up with the peg apparatus and with the gap apparatus, and I also found that the effect depended somewhat on the wording of instructions. Because the gap apparatus precluded participants dropping the pipe, I decided to use it for all of the remaining experiments. In the present experiment, I further explored the effect of instructions on the upper effect. My starting point was the observation that in the previous experiments, I provided participants with instructions that included three pieces of information, the side of the pipe that was the business end, the side to which the business end would be brought, and the height the pipe to which the pipe would be carried. All of this information was explicitly stated, which raised the question of how important that explicit specification was for the upper effect? If the explicit framing of a business end and a target direction were removed, would participants still show the upper effect? I addressed this question in Experiment 3.

In Experiment 3, I stripped the previous experiments of the explicit meaning within the instructions. I removed mention of a business end. I also removed from the verbal instructions any explicit mention of a target direction. I decided to keep the target height, as it would still be important for participants to know to which height they were required to rotate. I predicted that participants would adopt one of two alternatives. Any given participant would always rotate the pipe clockwise or counter-clockwise. This prediction contrasted with what participants did in Experiments 1 and 2 where they showed the upper effect, which I defined with reference to the business end. It was possible that participants have a general preference to switch between clockwise and counter-clockwise rotations. It was important to check for this and I did so in Experiment 3.

Because there was no business end in Experiment 3, I needed a way of analyzing the data that was commensurate with the analysis of data in Experiments 1A, 1B, 2A, and 2B, where there was a business. Here the likelihood of rotating the pipe clockwise was useful.

In Experiments 1 and 2, when participants performed the upper effect, they rotated the pipe clockwise to right-specified targets and counter-clockwise to left-specified targets. Figure 15 shows the number of participants who showed various numbers of clockwise rotations out of a maximum possible number of 24 trials per participant. As seen in the figure, the peak of the distribution was at 12, or half of 24. The prediction of Experiment 3 was that the same way of plotting the data would yield a U-shaped function rather than a peak-in-the-middle distribution.

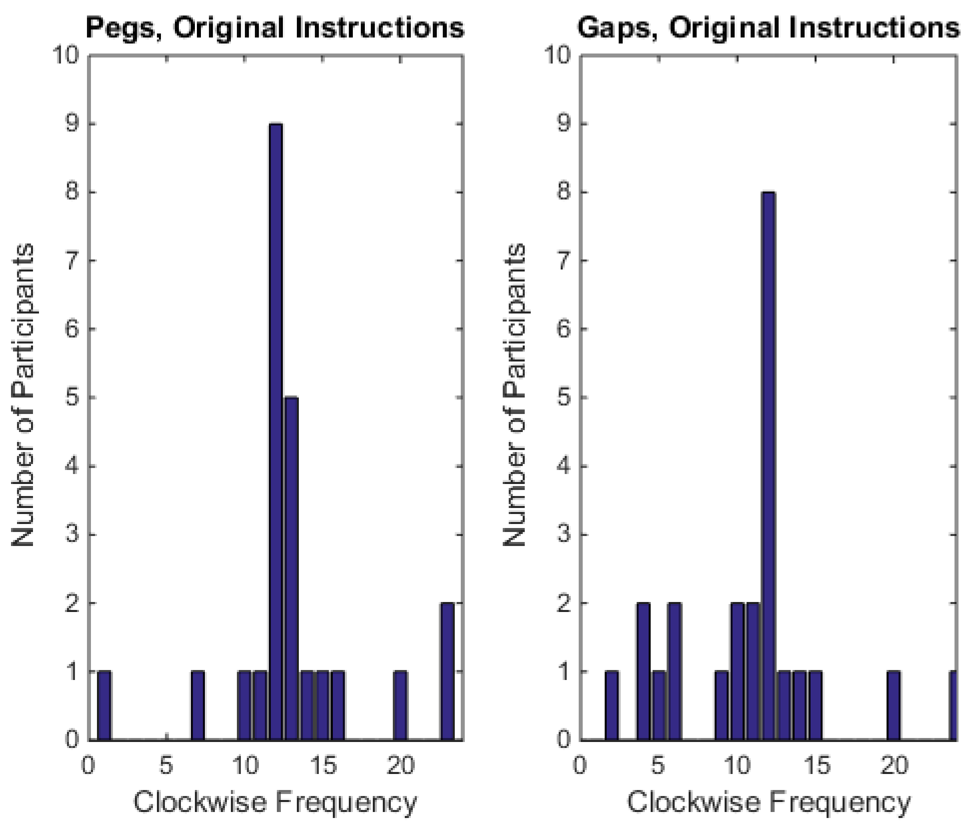

Figure 15. Frequency of clockwise rotation. The data are shown for Experiment 1A and Experiment 2A. Participants in the middle of the distribution most strongly show the upper effect as they are alternating between clockwise and counter-clockwise rotations.

Experiment 3 – Rotation Task with Semantically-Stripped Instructions

Method

Participants

Twenty-four participants from The Pennsylvania State University volunteered for Experiment 3 in exchange for course credit. The age of the participants ranged from 18 to 29 (*M* = 19.17). Participants completed a short form of the Edinburgh handedness inventory (Oldfield, 1971). Twenty-three participants reported being right-handed and one reported being left-handed. None of the participants reported any neurological deficits.

Design of Apparatus

The same gap apparatus was used as in Experiment 2A and 2b. There were no modifications.

Procedure

Participants followed a procedure similar to the ones in the previous studies. In each trial, participants listened to an instruction from the experimenter that indicated which height they were required to rotate the pipe. For the three target heights of 1.80 m, 1.34 m, and 0.88 m, the respective instructions from the experimenter were, “A,” “B,” and “C.” After hearing the height specification, the participant used the grasp orientation(s) of his or her choice (grasp orientations could, and often did, change during the participant's movement in any given trial), rotated the PVC pipe 180 degrees either clockwise or counter clockwise into the named position. As in the previous studies, the pipe was always raised or lowered as well as rotated. The pipe was always kept at the same height as where it started.

Unlike the previous specifications, there was no mention of the colored end of the pipe or the colored target gaps. There was no explicit indication of these details that should have biased the participants to a particular business end. Participants were told that the colored ends and the marked target gaps were being used for another study being conducted in the lab.

All 24 participants experienced 24 trials, modified from the original experiments (2 possible pipe orientations at each starting position x 2 possible orientations at each target position x 3 target heights x 2 trials per condition). Trials were created using a Latin square design. Trials were arranged in pseudo-random order so that the ending position of the pipe in each trial was the starting position for the following trial. When all 24 trials were completed, the participant was debriefed and thanked for his or her participation.

Results

Data Analysis

For each participant in all of the experiments, I calculated their usage of a dominant strategy. First, I calculated the number of clockwise rotations and the number of counter-clockwise rotations for each participant. I next determined which rotation was more dominant and used that frequency value to calculate the mean usage of a dominant strategy. To do this, I took the frequency of the dominant strategy and divided it by the 24 possible trials that participants performed. Each participant's dominant strategy mean could have ranged from 0.5 to 1.0. A mean of 0.5 meant that the participant rotated 12 times clockwise and 12 times counterclockwise. A 1.0 mean indicated that participants used a single dominant strategy (i.e., always rotated clockwise or always rotated counter clockwise).

Semantically Stripped Framing

In the results reported here, I was interested in how participants varied falling into a dominant strategies between Experiments 1 and 2 compared to the A-B-C semantically stripped instructions in Experiment 3 (Figure 16). I performed an independent sample t-test of the means of the dominant strategies of each participant in each study. The analysis revealed a statistically significant difference in adhering to a dominant clockwise or counter clockwise rotation strategy between the original 'pipe-target' or reversed 'target-pipe' instructions ($M = .70$, $SD = .17$) and the semantically stripped instructions in Experiment 3 ($M = .93$, $SD = .13$); $t(118) = -6.248$, $p < .001$. The usage of a dominant strategy in Experiment 3 ($M = .93$) strongly contrasted with Experiment 1A ($M = .61$) and Experiment 2A ($M = .63$) where the upper effect was strongest.

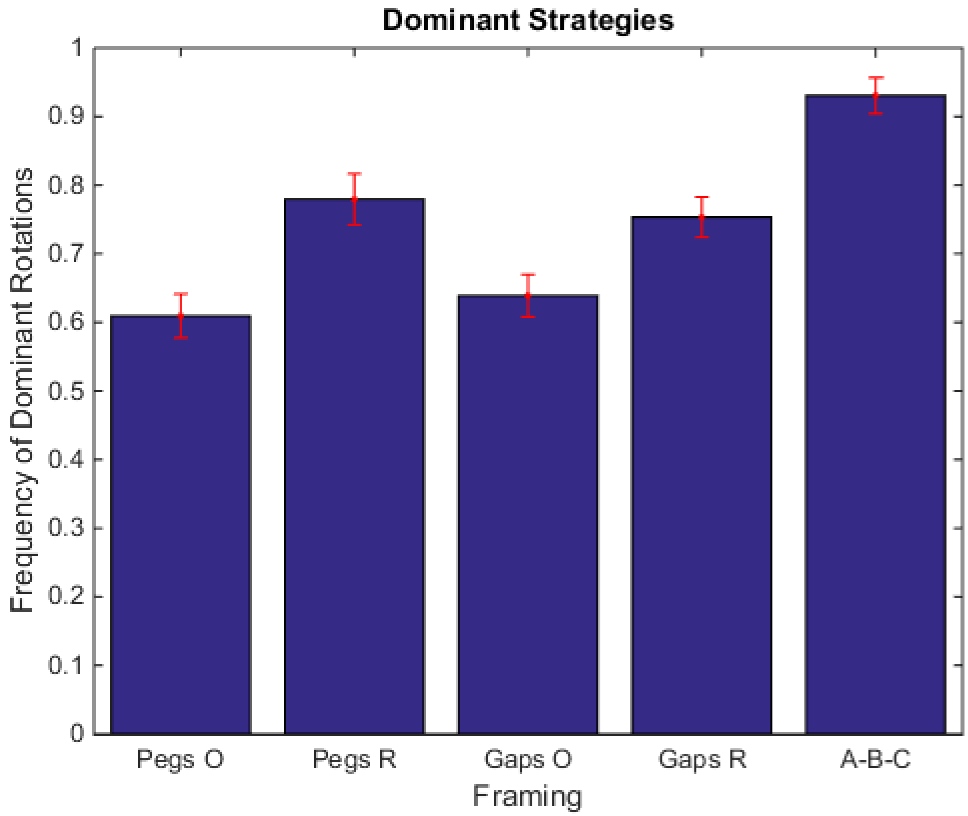

Figure 16. Average frequencies of dominant strategy usage. The data are shown for Studies 1-3.

The prediction of Experiment 3 was that plotting the data would yield a U-shaped function (Figure 17) rather than a peak-in-the-middle distribution as in Experiments 1A and 2A. As seen in the figure, this was the case, where the numbers of clockwise rotations out of a maximum possible number of 24 trials per participant is plotted.

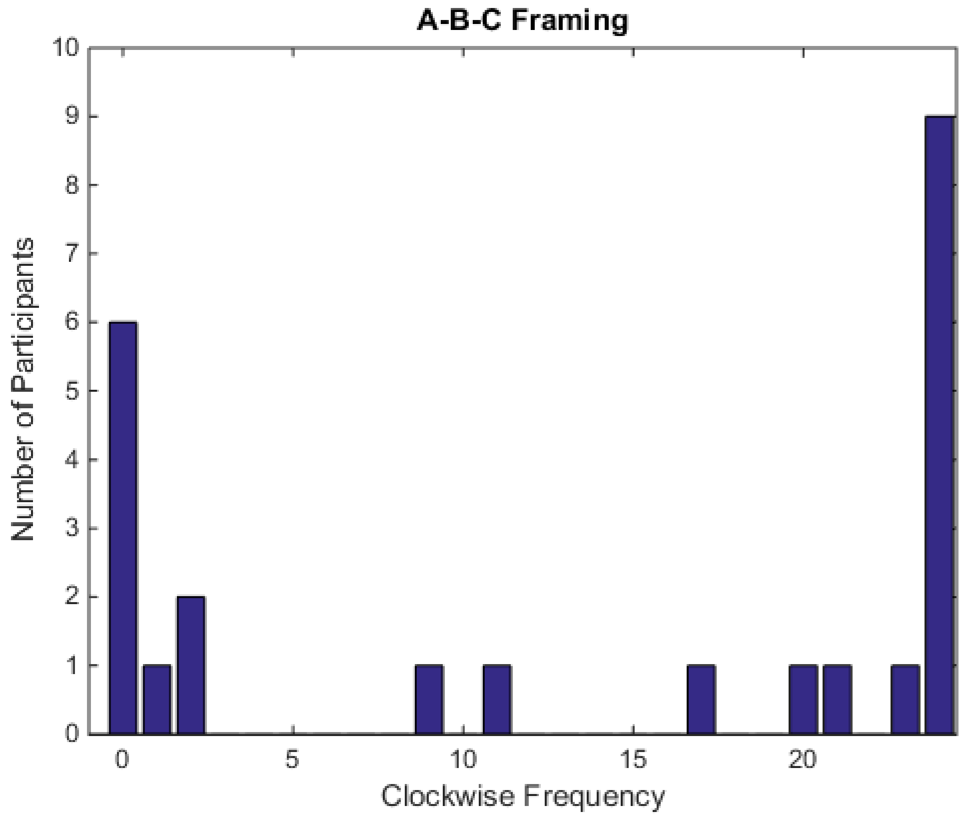

Figure 17. Frequency of clockwise rotation. The data are shown for Experiment 3. The U-shaped distribution show preferences for a dominant strategy.

Discussion of Experiment 3

In Experiment 3, I evaluated how important the semantic information presented in the instructions is to the upper effect and the implicit constraint being used by the participants. In Experiments 1 and 2, where participants heard the specification of a business end to a target location, they adjusted and alternated between clockwise and counter-clockwise rotations to perform the upper effect. In Experiment 3, I semantically stripped the instructions. Participants only heard a specified height. If the explicit instructions found in Experiment 1 and 2 caused participants to mentally represent the task in a way that brought about the upper effect, then I predicted in the absence of the explicit instructions, participants should follow a different rotation pattern. Specifically, if participants represented the semantically stripped task differently, I predicted that they would have adopted a single dominant rotation.

The results of Experiment 3 supported my prediction. Participants adopted a single dominant strategy. Participants rotated mostly clockwise or they rotated mostly counter-clockwise. This contrasted with Experiments 1 and 2, where participants alternated between clockwise and counter-clockwise rotations, which demonstrated a desire to do the upper effect.

This finding highlighted the importance of the explicit information presented in the verbal instructions. It demonstrated that when participants are presented with explicit mention of a business end and a target direction, they imposed their own implicit constraint as manifested in the upper effect. Participants assigned some form of cognitive importance to the business end. It appeared that participants mentally represented the stripped task differently. There was no evidence that they applied an additional implicit constraint. At a physical level, Experiment 3 required participants to rotate a pipe 180 degrees every trial, no different than what was required of them in Experiments 1 and 2. But similar to the reports of cognitive framing effects in high-level decision- making, participants responded to the task differently based on the instructions.

Chapter 5

Perceptual Guiding Constraints on Gap Apparatus

In Experiment 1 and Experiment 2, I explored the impact of semantic constraints in a bimanual rotation task. I found that participants adjusted their rotational direction depending on the instructions. This strategy is best captured as the upper effect and involves a clockwise rotation of the pipe to right targets and counter-clockwise rotations to left targets. Participants were never explicitly told that they had to perform the task in this way. Further evidence that the instructions played a critical role in the upper effect was obtained in Experiment 3 where I semantically-stripped the specifications to just give information about target height. There was no mention of a business end of the pipe or a target direction. The participants in Experiment 3 followed dominant strategies, showing a high frequency of either clockwise rotations or counter-clockwise rotations. These findings were in direct contrast with Experiment 1 and Experiment 2, where following a dominant direction of rotation would have reduced the upper effect to chance.

But these findings also raised another important question: Can the upper effect still be demonstrated in the absence of verbal instructions? The findings of Experiments 1-3 highlighted the role of verbal instructions and the semantics involved in those instructions, but what more can I say of the visual component of this phenomenon? In Experiment 4 I addressed this question by presenting the instructions using nonverbal cues via a computer. The computer monitor displayed to the participants the final position to which they would have to bring the pipe given its current position (the last trial’s final position or, in the first trial, the position it was in because the experimenter put it there). If the upper effect reflected a deep cognitive constraint, not tied specifically to language (or verbal instructions), the upper effect would remain even if language were not used. Conversely, if the upper effect reflected a constraint that was tied specifically to language (or verbal instructions), then the upper effect would disappear.

Another question remained unanswered by Experiments 1 and 2: Is the upper effect a mere byproduct of the location of the business end along the pipe? In all of the previous experiments, the blue and green tapes were always placed on the distal ends of the pipe. Was this important? Did subjects want to see a big sweeping arc of the business end traveling through the upper part of the workspace perhaps for some reason yet to be determined?

I addressed this question in Experiment 4 by introducing a new manipulation. I assigned participants at random to two groups based on the location of the business end, the “outer” group and the “inner” group (Figure 18). In the outer condition group, the business end was located just as in Experiments 1 and 2 (i.e., as distally as possible). In the inner conditions, the business end was brought more proximal, but still not fully centered. If the upper effect was just the result of the business end being located on the far ends of the pipe, then I predicted the upper effect would go away in the inner group.

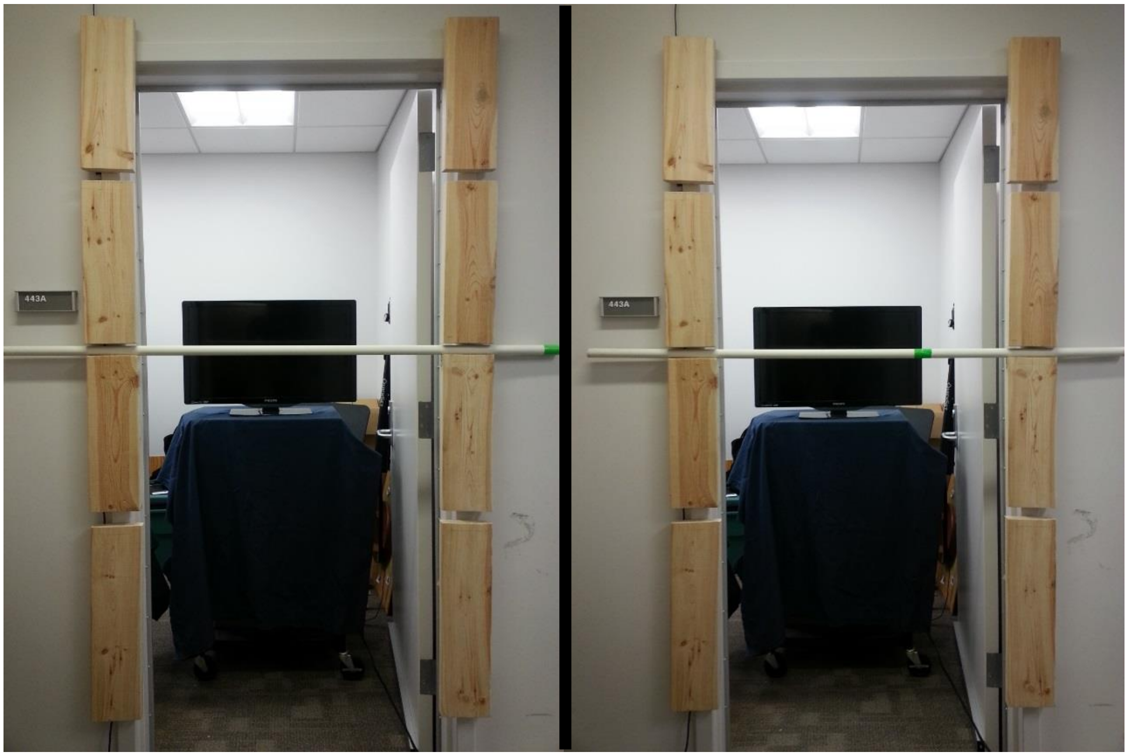

Figure 19. Two pipe groups. Left panel shows outer and left panel shows inner. Only green business ends are shown.

Experiment 4 – Visual Cue Presentation

Method

Participants

Twenty-four participants from The Pennsylvania State University volunteered for Experiment 4 in exchange for course credit. The age of the participants ranged from 18 to 20 (*M* = 18.42). Participants completed a short form of the Edinburgh handedness inventory (Oldfield, 1971). Twenty-two participants reported being right-handed and two reported being left-handed. None of the participants reported any neurological deficits.

Design of Apparatus

The gap apparatus was used from Experiments 2A and 2B (Figure 19). The wooden boards were stripped of the duct tape demarcations. Modifications were made to the PVC pipe. Whereas in Experiments 1-3, there was green duct tape on one end of the pipe and blue duct tape on the other end of the pipe, for this study, I removed one of the tapes. For the outer group, half the subjects had the blue tape at one end of the pipe and half the subjects had green tape at one end. Similarly, for the inner group, half the subjects had blue tape near the middle of the pipe (17 cm away) and half of the subjects had green tape near the middle of the pipe (17 cm away).

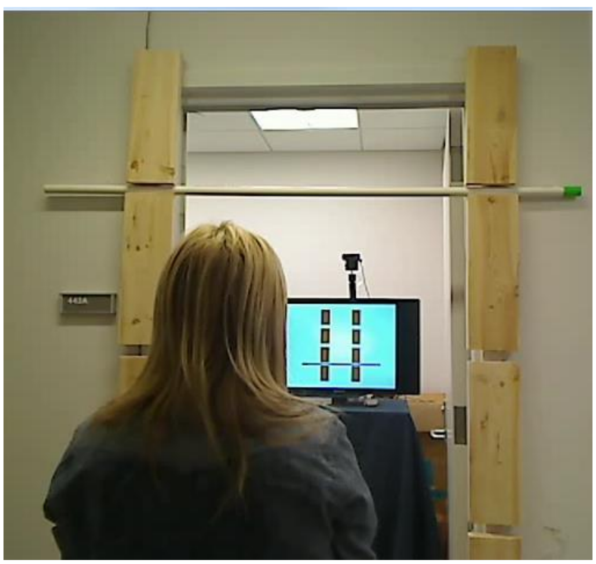

Figure 20. Gap apparatus with monitor displaying the trial’s target orientation.

Facing 0.61 m away from the participants inside the door frame that held the gap apparatus was a large computer monitor (32-in. Philips Model 32PFL4507/F7, Koninklijke Philips N.V., Amsterdam, The Netherlands). Visual cues in each trial were presented to participants on the monitor. Cues were designed in Microsoft PowerPoint and advanced every trial by research assistant using a presentation clicker (Logitech, LOG910001354).

Procedure

Participants were divided into two groups: inner pipe group (6 participants each for the green marked pipe and the blue marked pipe) and outer pipe group (6 participants each for the green marked pipe and the blue marked pipe).

In each trial, participants faced the apparatus with the pipe placed horizontally on the apparatus. At the start of each trial, a grey screen appeared on the monitor, signaling the start of a new trial. Next, the monitor displayed the target orientation of the pipe. The participants then used the grasp orientation(s) of his or her choice (grasp orientations could, and often did, change during the participant's movement in any given trial) and rotated the PVC pipe 180 degrees either clockwise or counter clockwise into the cued target orientation. As in the previous study, the pipe was always raised or lowered as well as rotated. The pipe was never removed, rotated, and inserted at the same height as where it started. No mention of the business end of the pipe was ever explicitly stated to the participant.

The visual cue displayed to the participants showed the next target position of the pipe (i.e., its height and orientation, both of which always differed from the initial position). When the PVC pipe was successfully inserted horizontally across both gaps at the designated target height, correctly matching the visual cue on the computer monitor, the trial ended and the participant was asked to return his or her hands to his or her sides to await the next specification. In cases when the pipe was brought to an incorrect position, the experimenter repositioned the pipe at that trial's start orientation. The participant then recompleted the trial. This happened infrequently.

All participants experienced 24 trials (2 possible pipe orientations at each starting position x 2 possible orientations at each target position x 3 target heights x 2 trials per condition) arranged in a Latin square design. Trials were arranged in pseudo-random order so that the ending position of the pipe in each trial was the starting position for the following trial. When all 24 trials were complete, the participant was debriefed and dismissed.

Results

Factors Affecting Rotation Direction

Even though there was no explicit mention of the business end, I defined it as the end on whose side the tape was located, either at the end of the pipe or toward its interior. I subjected the mean frequencies of clockwise rotations (Figure 20) to a repeated-measures ANOVA whose design was 2 (target direction, left side or right side) x 3 (target height, 1.80 m or 1.34 m or 0.88 m). The ANOVA revealed a significant effect of target direction $F(1, 22) = 896.349$, $p < .001$. A pairwise comparison with a Bonferroni correction showed that the clockwise frequency for left targets ($M = 0.04$) was significantly lower from the right targets ($M = 0.96$), $p < .001$.

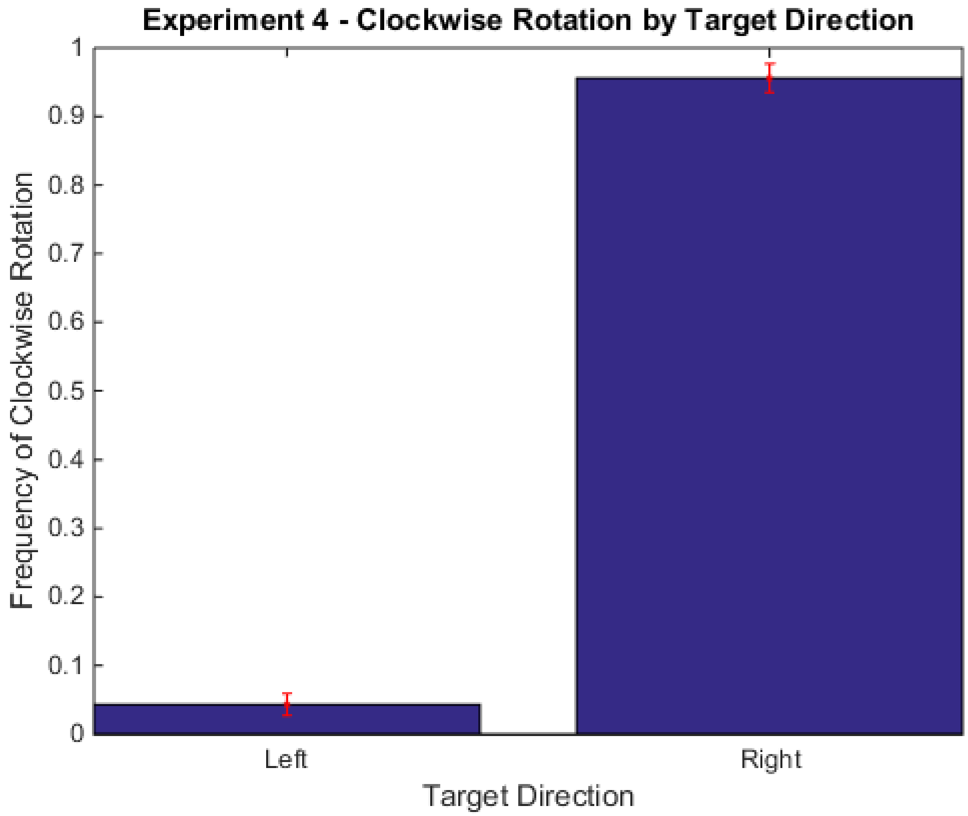

Figure 21. Frequencies of clockwise rotations for left and right targets in Experiment 4. The error bars represent ±1 SE.

Factors Affecting the Upper Effect

To determine whether participants displayed any effects of target direction or height of target of the rotational choice for their task, I subjected the mean likelihoods of the upper rotations to a repeated-measures ANOVA whose design was 2 (target direction, left or right) x 3 (target height, 1.80 m or 1.34 m or 0.88 m) x 2 (pipe group: inner or outer).

The ANOVA revealed no significant effect of pipe group $F(1,22) = .294$, $p > .05$. The ANOVA revealed a significant interaction (Figure 21) between target direction and location of the business end (i.e. inner or outer), $F(1,22) = 5.418$, $p = .03$. For both the inner and the outer conditions, the upper effect remained strong. The interaction shows a slight decrease in the inner pipe group when the target was on the right side of the apparatus. Overall, the upper effect remained well above chance. The results revealed no other significant main effect or interactions, $p > .05$.

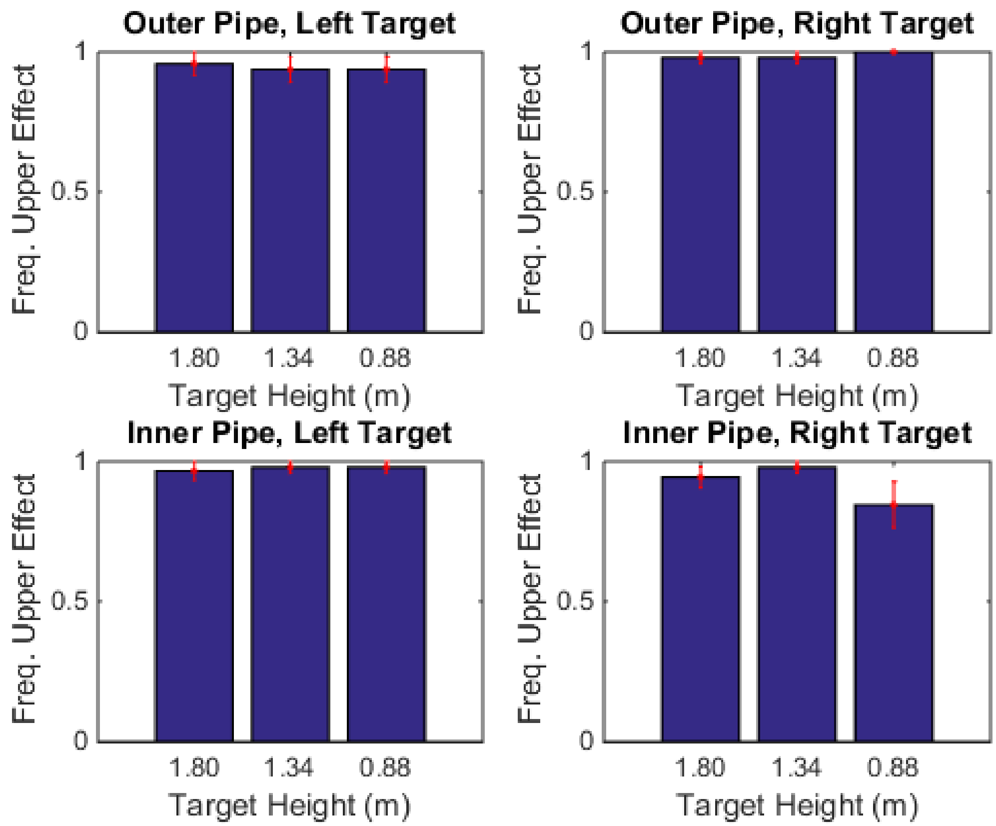

Figure 22. Frequencies of upper effect at different heights, target locations, and between the inner and outer groups. The error bars represent ±1 SE.

Discussion of Experiment 4 Results

In Experiment 4 I asked whether or not the upper effect depended on the presence of verbal instructions. The results of Experiment 4 strongly suggest that this was not the case, as I found the upper effect was even stronger than in the verbal instructions. In Experiment 4, I also asked whether the upper effect was a mere byproduct of the location of the business end on the pipe. I found in both the inner and the outer conditions that the upper effect remained strong and well above chance.

Chapter 6

Rotation Task "Blindfolded"

Another question has remained in all of the discussed experiments. Did participants perform the upper effect because they wanted to keep the business end of the pipe always visible? Asked another way, were participants simply avoiding the lower workspace because they wanted to avoid occluding the business end of the pipe? Rotating the pipe down through the lower workspace would cause the business end to become occluded when the subject's arm hid the business end. If the business end were to go down, violating the upper effect, then there would be a point where the participant's arm would block the business end. In Experiment 5, I tested this possibility by asking participants to do the task blindfolded. If the upper effect was due to participants wanting to be able to see it at all times, the upper effect should disappear when no vision was available. If the upper effect was not the result of occlusion avoidance, then the phenomenon should remain.

Experiment 5 – Rotation Task with Blindfold

Method

Participants

Twenty-four participants from the Pennsylvania State University community participated in exchange for course credit. The age of the participants ranged from 18 to 25 (M = 19.08). Participants completed a short form of the Edinburgh handedness inventory (Oldfield, 1971).

Twenty-two participants reported being right-handed and two reported being left-handed. None of the participants reported any neurological deficits.

Design of Apparatus

The gap apparatus used in Experiment 2 was used for Experiment 5. There were no modifications to the apparatus. Additionally, participants were provided a Rite Aid Renewal luxury padded sleep mask to wear during trials.

Procedure

Participants followed a similar procedure to Experiment 1 and Experiment 2. Prior to the start of each trial, participants were told to look at the apparatus and take note of the pipe orientation in its current placement. When ready, participants placed the blindfold over their eyes to fully occlude their vision. Once the blindfold was in place, participants told the experiment that they were ready for the trial to begin. In each trial, they listened to an instruction from the experimenter such as “green end to blue C.” Then they used the grasp orientation(s) of his or her choice (grasp orientations could, and often did, change during the participant’s movement in any given trial), rotated the PVC pipe 180 degrees either clockwise or counter clockwise into the named position. The pipe was always raised or lowered as well as rotated. The pipe was never removed, rotated, and inserted at the same height as where it started. After the rotation was completed and the pipe was in position, participants removed their blindfold and waited for the next trial.

The specifications of instructions were the same used in Experiment 1a and 2a. The trial instruction began with a specified pipe end followed by a specified target location.

All 24 participants experienced 24 trials (2 possible pipe orientations at each starting position x 2 possible orientations at each target position x 3 target heights x 2 color specifications) arranged in a Latin square design. Trials were arranged in pseudo-random order so that the ending position of the pipe in each trial was the starting position for the following trial. When all 24 trials were complete, the participant was debriefed and dismissed.

Results

Factors Influencing Rotation Direction

To determine whether participants had a particular preference in clockwise or counterclockwise rotation as a result of specified target direction or target height (Figure 22), I subjected clockwise rotation means of each participant to a repeated-measures ANOVA whose design was 2 (target direction, left side or right side) x 3 (target height, 1.80 m or 1.34 m or 0.88 m).

The ANOVA revealed a significant effect of target direction, $F(1, 23) = 95.684$, $p < .001$. Pairwise comparisons showed that there was a statistically significant difference for clockwise preference when the target was on the right ($M = .86$) compared to when the target was on the left ($M = .21$), $p < .001$.

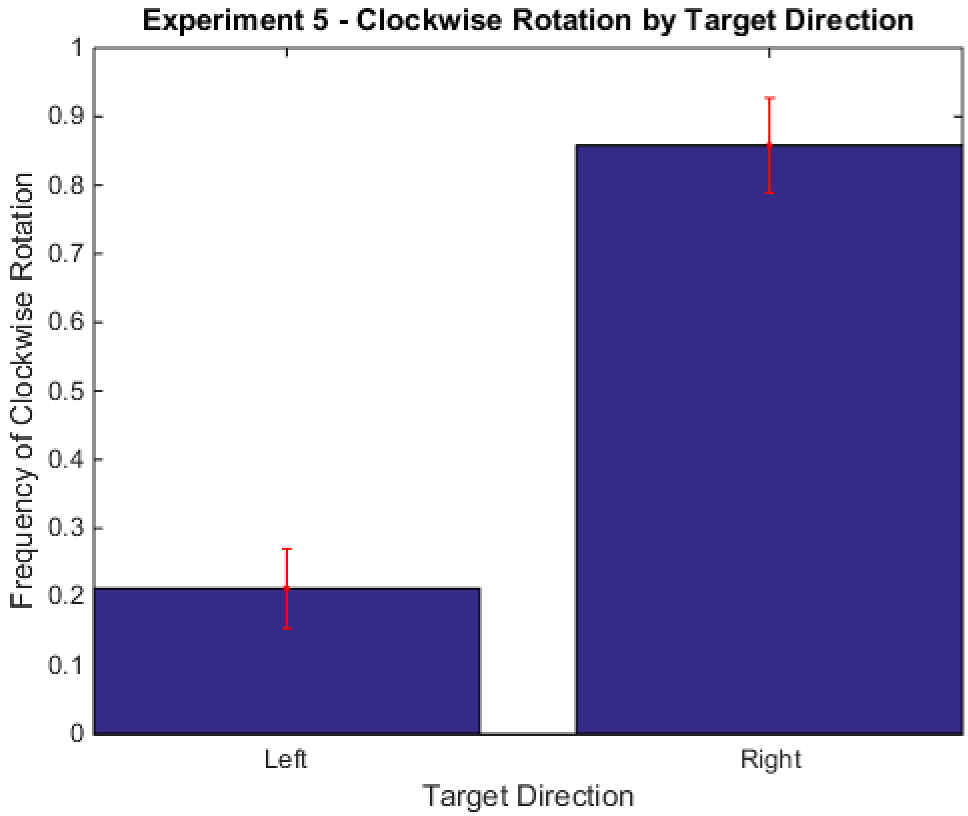

Figure 23. Frequencies of clockwise rotations for left and right targets in Experiment 5. The error bars represent ±1 SE.

The ANOVA revealed a significant two way interaction between target direction and target height F(2, 46) = 11.044, $p < .001$. Figure 23 illustrates the interaction. When the targets were on the left, clockwise rotations were slightly higher in frequency for heights 1.34 m and 0.88 m, but fell significantly at 1.88 m. The results revealed no other significant main effect or interactions, $p > .05$.

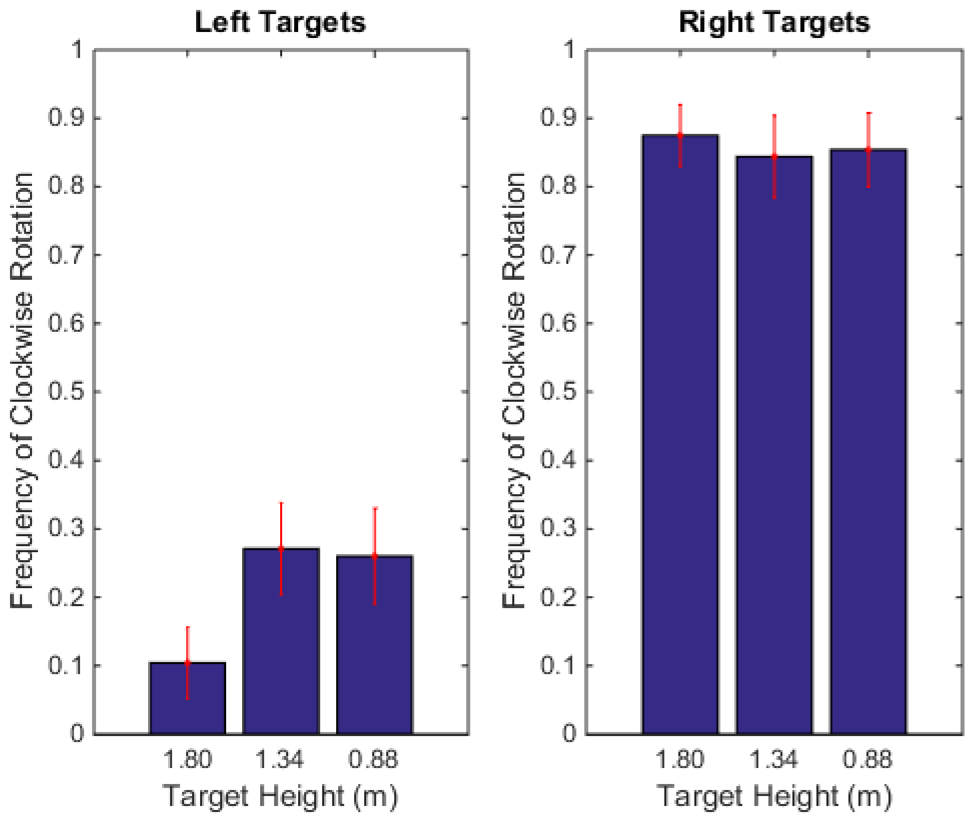

Figure 24. Frequencies of clockwise rotations for left and right targets at different heights in Experiment 5. The error bars represent ±1 SE.

Factors Influencing the Upper Effect

To better understand the upper effect, I asked whether it depended on the target orientation and the height of target (Figure 24). I subjected the mean likelihoods of the 'upper' rotations per participant to a repeated-measures ANOVA whose design was 2 (target pipe orientation, blue on left and green on right or green on left and blue on right) x 3 (target height, 1.80 m or 1.34 m or 0.88 m).

The ANOVA revealed a significant effect of target height $F(2, 46) = 5.327$, $p = .008$. The frequency of the upper effect varied along the three target heights of 1.80 m ($M = .88$), 1.34 m ($M = .77$) and 0.88 m ($M = .81$). Pairwise comparisons with a Bonferroni correction showed a significant difference when comparing a target height of 1.80 m with the 1.34 m and 0.88 m target heights, $p < .05$. There is no significant difference between 1.34 m and 0.88 m, $p > .05$. Mauchly's test for the assumption of sphericity were not violated. The results revealed no other significant main effect or interactions, $p > .05$.

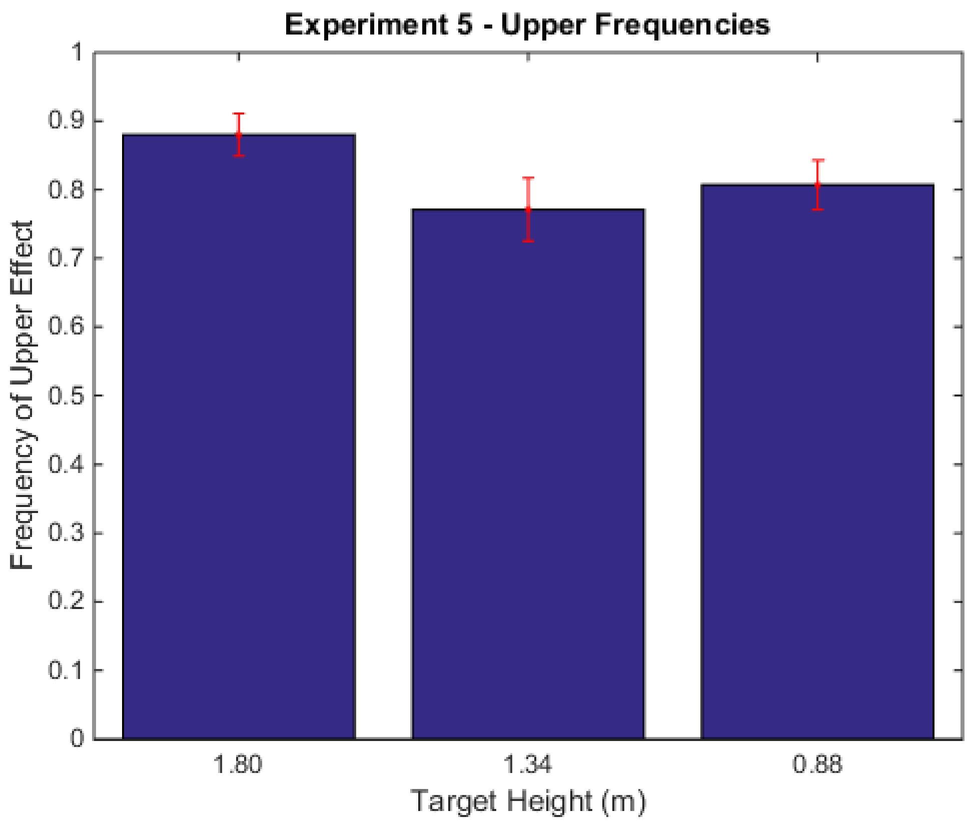

Figure 25. Frequencies of upper effect at different heights in Experiment 5. The error bars represent ±1 SE.

General Discussion of Experiment 5

In Experiment 5, I addressed the question of whether or not the upper effect was due to the desire to keep the business end of the pipe visible in the workspace. By bringing the business end of the pipe up, participants would have avoided the arm's occluding the business end. I tested this hypothesis by asking subjects to do the task blindfolded. The results let me reject this hypothesis. The upper effect remained strong. This suggests that the upper effect was not driven by the desire to avoid occlusion. Even in the absence of visual feedback during the trials, participants still showed the upper effect. I cannot rule out the possibility that within the participant's mental image, there might have still been occlusion, but this does not seem like a parsimonious account of the results.

Chapter 7

General Discussion

I have now reported five experiments that have introduced and evaluated a new phenomenon, the *upper effect*, as I call it. The upper effect reflects a planning strategy in which participants chose to rotate a pipe to target positions such that the end of the pipe end to which attention was drawn (the "business" end) was usually moved through the upper workspace. *A priori*, individual participants could have relied on a default strategy of always turning the pipe clockwise or always turning the pipe counter-clockwise. This was not what they did, however. The upper effect turned up in all the experiments where I expected it to after the first experiment in which it arose unexpectedly. In this final chapter of the thesis, I will review the experiments that I did and then turn to overarching theoretical implications of this work plus suggestions for future research.

Summary of Experiments

In Experiment 1, I tested participants on the bimanual rotation task using a peg apparatus. Here, I discovered the upper effect. In Experiment 1A, I instructed participants to bring a specified business end of the pipe to a specified target height and side. The instructions were ordered such that I first specified the business end, followed by the target location. Participants demonstrated the upper effect.

In Experiment 1B, I sought to better understand the basis of the upper effect. I changed the ordering of the terms of the instructions, such that I first offered participants the target location followed by the business end specification. Participants still demonstrated the upper effect, but not as strongly as in Experiment 1A. This suggested a potential semantic sensitivity to this phenomenon.

In Experiment 2, I tested the hypothesis that the upper effect arose because participants sought to exploit gravity. If true, that meant participants used an understanding of physics of the movements and affordances of the pipe and peg apparatus. If participants exploited gravity, they simply dropped the pipe onto the pegs. Alternatively, if this simple biomechanics hypothesis did not account for the upper effect, then I predicted participants would still show it. I tested this *gravity* hypothesis in Experiment 2 by modifying the original apparatus. I replaced the pegs with gaps, which forced participants to have to make a concerted effort to both withdraw and insert the pipe at the start and end of each trial. It was no longer physically possible for participants to drop the pipe. With the gaps implemented in the new apparatus design, the upper effect was still replicated, so I rejected the gravity hypothesis.

With the gap apparatus (Experiments 2A and 2B), as with the peg apparatus (Experiments 1A and 1B), I found that the upper effect depended somewhat on the wording of the instructions. With both kinds of apparatus, the upper effect was somewhat stronger when the business end was mentioned before the target location than when the target location was mentioned before the business end. In Experiment 3, I addressed another question related to instructions: How important was the *explicit* specification for the upper effect? I tested to see whether participants still showed the upper effect when the verbal instructions did not include mention of a business end of the pipe or a target direction. Instead of giving such verbal instructions, I simply said A, B, or C to designate the target height. 180 degree rotations were always required. In this situation, participants rotated in a single dominant way, either clockwise for some participants or counter-clockwise for others. Thus, I was able to knock out the upper effect when no business end was mentioned. The data from Experiment 3 show as well that participants simply wanted to switch rotation directions and, given that desire for variety, chose, for one reason, or another to map those directions to the business end in the way captured by the upper effect.

In Experiment 4, I addressed the question of whether the upper effect still held in the absence of verbal instructions. I presented participants with nonverbal cues on a computer monitor. The monitor displayed the target orientation and target height for the pipe. I also modified the pipe so it only had one colored end and the colored end was either in an outer or inner position along the pipe. The participants were never explicitly told to pay attention to the colored end of the pipe. I predicted that if participants were implicitly treating the colored end of the pipe as the business end, then that end would go through the upper part of the workspace during the rotation. I found that this was the case. In fact, participants showed the upper effect even more strongly than in the previous studies. The upper effect was essentially equally strong in the inner and outer groups. This let me rule out the possibility that subjects wanted to see a big sweeping arc of the business end traveling through the upper part of the workspace.

Finally, in Experiment 5, I checked whether the upper effect resulted from participants' wanting to avoid visual occlusion of the business end by their own arms. Rotating the pipe down through the lower workspace would have caused the business end to become occluded when the subject's arm hid the business end. To test this possibility, I asked participants to wear a blindfold while moving the pipe. They still showed the upper effect, which suggested that the desire to have continual sight of the business end was not the source of the upper effect.

Having identified what the upper effect is *not* due to, I must confess that I have not succeeded yet in nailing down what the upper effect *is* due to. Doing so is, of course, the main remaining challenge.

Toward addressing this challenge, I can suggest several lines of future research. Cognitive-linguistics manipulations can be used to shed light on how the variation in syntax in the instructions between the original pipe-to-target and reversed target-to-pipe ordering impacts the understanding and representation of the task. A deeper evaluation of the syntax can be used to better understand how participants are cognitively processing the matching of the instructions to the typical ordering of nouns and verbs in normal dialogue. The sensitivity of the ordering of instructions could also be used to shed light on how bilinguals perform the task. What impact does syntactic structuring play in action words across speakers of different languages?

Also, monitoring of eye movements would be useful. Eye-tracking could prove potentially interesting. It might be that the way the eyes move predicts how the business end is moved. Conceivably, then, the eye-movement path establishes the template for the business end to follow. If that were the case, showing an animation of the pipe moving through one arc or another might strongly bias the trajectory that is chosen.

Finally, the properties of the to-be-moved object can be varied to better understand the dependency of the upper effect on the specific type of pipe that was used here. Would the effect still hold with a heavier pipe of the same size as the one I used? Would the effect still hold with a much shorter (or much longer) pipe? Would the effect go away with practice? And would the effect depend on the difficulty of aiming to bring the business end to its target site? What would happen, for example, if one gap were very wide and the other gap were much narrower? If the upper effect is a reflection of visual attention, as I suspect it is, then it should depend strongly on the relative widths of the targets.

Implications for Stimulus-Response Compatibility

The discussion of preferring certain strategies for specific tasks, or favoring a solution to a problem based on a specific framing, also offers the opportunity to discuss stimulus-response compatibility (SRC). Researchers studying SRC effects (e.g. Brebner, Shephard, & Cairney, 1972; Shulman, & McConkie, 1973) have referred to advantages to response time when congruent stimuli and responses are paired (e.g., when targets on the right are matched with right-hand responses), and conversely, disadvantages when incongruent stimuli and responses are paired (e.g., when targets on the left are matched with right-hand responses).

Directly related to the bimanual rotation task described in this thesis is SRC literature on the control of steering wheels (e.g. Guiard, 1983; Murchison & Proctor, 2013). When one uses a steering wheel, it is common to discuss the direction of wheel rotation in terms of the direction of motion of the top of the wheel. When one says that the wheel is turning right, it means that the top of the wheel is going right, though the bottom of the wheel is actually going left, and vice versa, of course, for turning the wheel to the left.

In one study that evaluated SRC effects in wheel rotation (Guiard, 1983), participants rotated a wheel either clockwise or counter-clockwise when stimuli were presented in left or right locations. Participants were quicker to initiate clockwise than counter-clockwise rotations when moving to stimuli presented on the right, but they were quicker to initiate counter-clockwise than clockwise rotations when moving to stimuli presented on the left. A similar finding was obtained by Murchison and Proctor (2013). My results, which concern choices of rotation directions rather than reaction times to initiate prescribed rotation directions, map onto this finding. Conceivably, the RT differences obtained before and the upper effect discovered here reflect the same underlying perception-action rule or soft constraint.

Future SRC research could ask questions similar to the ones I presented in my thesis. Is there a mapping, or a preference, for the selection of certain actions based on various verbal cues (e.g. differences in framing of instructions) and visual-perceptual cues? I found that participants used strategies predicted by SRC wheel rotation effects (Guiard, 1983; Murchison & Proctor, 2013). Importantly, this provides an extension of SRC effects into an ecological task. Future research can evaluate how the semantic and perceptual guiding constraints described here interact with SRC effects.

Framing Effects in Motor Planning

The work presented here contributes to the growing body of literature that explores higher-order processes involved in the planning and execution of movements. One such study that I find particularly helpful and relevant was by Franz and McCormick (2010), who described semantic, perceptual, and conceptual unifying constraints for physical action planning. The upper effect, and the semantic and perceptual constraints governing it, extend these conceptual constraints. Both the semantic and perceptual manipulations used in the bimanual rotation task demonstrated how higher-order cognitive processes guide one's movements and strategies.

That higher-order constraints were brought to bear in this action task calls to mind the work on Kahneman on cognitive framing effects. In his book *Thinking, Fast and Slow*, Kahneman ascribed the heuristics captured by cognitive framing effects to fast thinking as needed to make rapid decisions in the everyday world, including in the savannahs and jungles from which humans evolved. Thinking fast, Kahneman argued, required adaptive ways of processing information that might not always be the strictly logical but they get the job done when one's survival is at stake. Slow, deliberate thinking, by contrast, might be more logical or rational in the long run but be less adaptive in the short run.

If Kahneman's conjecture is correct, cognitive framing should be manifested in physical action planning. Kahneman made no mention of such effects in his book, probably reflecting his specialization in higher-order thinking rather than perceptual-motor skills. Here, I have introduced evidence that cognitive heuristics are expressed in physical action. It is conceivable, though certainly not provable based on the evidence presented here, that the cognitive heuristics expressed in physical action set the stage for the cognitive heuristics that have been more commonly discussed in cognitive psychology and behavioral economics. This would make sense because, otherwise, it would remain a mystery why or from where those heuristics originated.

Because other cognitively mediated action-planning effects may also be viewed as cognitive framing effects—the end-state comfort effect, for example (see Rosenbaum et al., 2012, 2014, for reviews)—the fact that non-human primates show those effects lends further credence to the hypothesis that cognitive heuristics related to business, finance and the like, derive from more elementary action planning. Testing the upper effect in non-human species could shed further light on this possibility.

References

Ariely, D. (2008). *Predictably irrational* (p. 20). New York: HarperCollins.

Brebner, J., Shephard, M., & Cairney, P. (1972). Spatial relationships and SR compatibility. *Acta Psychologica*, *36*(1), 1-15.

Cohen, R. G., & Rosenbaum, D. A. (2004). Where grasps are made reveals how grasps are planned: generation and recall of motor plans. *Experimental Brain Research*, *157*(4), 486-495.

Fischman, M. G., Stodden, D. F., & Lehman, D. M. (2003). The end-state comfort effect in bimanual grip selection. *Research Quarterly for Exercise and Sport*, *74*(1), 17-24.

Franz, E. A., & McCormick, R. (2010). Conceptual unifying constraints override sensorimotor interference during anticipatory control of bimanual actions. *Experimental brain research*, *205*(2), 273-282.

Frisch, D. (1993). Reasons for framing effects. *Organizational Behavior and Human Decision Processes*, *54*(3), 399-429.

Guiard, Y. (1983). The lateral coding of rotations: A study of the Simon effect with wheel-rotation responses. *Journal of motor behavior*, *15*(4), 331-342.

Hughes, C. M., & Franz, E. A. (2008). Goal-related planning constraints in bimanual grasping and placing of objects. *Experimental Brain Research*, *188*(4), 541-550.

Hughes, C. M., Haddad, J. M., Franz, E. A., Zelaznik, H. N., & Ryu, J. H. (2011). Physically coupling two objects in a bimanual task alters kinematics but not end-state comfort. *Experimental Brain Research*, *211*(2), 219-229.

Huhn III, J. M., Schimpf, K. A., & van der Wel, R. P. (2014). Symmetries in action: on the interactive nature of planning constraints for bimanual object manipulation. *Experimental brain research*, 1-9.

Janssen, L., Beuting, M., Meulenbroek, R., & Steenbergen, B. (2009). Combined effects of planning and execution constraints on bimanual task performance. *Experimental Brain Research*, *192*(1), 61-73.

Kahneman, D. (2011). Thinking, fast and slow. New York: Farrar, Straus and Giroux.

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica: Journal of the Econometric Society*, 263-291.

Kelso, J. A. S., Buchanan, J. J., & Murata, T. (1994). Multifunctionality and switching in the coordination dynamics of reaching and grasping. *Human Movement Science*, *13*(1), 63-94.

Kelso, J. S., Southard, D. L., & Goodman, D. (1979). On the coordination of two-handed movements. *Journal of Experimental Psychology: Human Perception and Performance*, *5*(2), 229.

Kühberger, A. (1998). The influence of framing on risky decisions: A meta-analysis. *Organizational behavior and human decision processes*, *75*(1), 23-55.

Kunde, W., & Weigelt, M. (2005). Goal congruency in bimanual object manipulation. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(1), 145.

Marteniuk, R. G., MacKenzie, C. L., & Baba, D. M. (1984). Bimanual movement control: Information processing and interaction effects. *The Quarterly journal of experimental psychology*, *36*(2), 335-365.

Murchison, N. M., & Proctor, R. W. (2013). Spatial Compatibility Effects With Unimanual and Bimanual Wheel-Rotation Responses: An Homage to Guiard (1983). *Journal of motor behavior, 45*(5), 441-454.

Rosenbaum, D. A. (2009). *Human motor control*. Academic Press.

Rosenbaum, D. A. (2005). The Cinderella of psychology: the neglect of motor control in the science of mental life and behavior. *American Psychologist*,*60*(4), 308.

Rosenbaum, D. A., Chapman, K. M., Coelho, C. J., Gong, L., & Studenka, B. E. (2013). Choosing actions. *Frontiers in psychology*, *4*.

Rosenbaum, D. A., Chapman, K. M., Weigelt, M., Weiss, D. J., & van der Wel, R. (2012). Cognition, action, and object manipulation. *Psychological bulletin*, *138*(5), 924.

Rosenbaum, D. A., Herbort, O., Weiss, D. J., & van der Wel, R. (2014). What's in a grasp? American Scientist (September-October issue), 102, 366-373.

Rosenbaum, D. A., Marchak, F., Barnes, H. J., Vaughan, J., Slotta, J. D., & Jorgensen, M. J. (1990). Constraints for action selection: Overhand versus underhand grips.

Shulman, H. G., & McConkie, A. (1973). SR compatability, response discriminability, and response codes in choice reaction time. *Journal of Experimental Psychology*, *98*(2), 375.

Skoyles, J. R. (1998). Speech phones are a replication code. *Medical hypotheses*, *50*(2), 167-173.

E. Stanovich, K., & West, R. F. (1998). Individual differences in framing and conjunction effects. *Thinking & Reasoning*, *4*(4), 289-317.

Swinnen, S. P., Lee, T. D., Verschueren, S., Serrien, D. J., & Bogaerds, H. (1997). Interlimb coordination: Learning and transfer under different feedback conditions. *Human movement science*, *16*(6), 749-785.

Thaler, R. (1980). Toward a positive theory of consumer choice. *Journal of Economic Behavior & Organization*, *1*(1), 39-60.

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, *211*(4481), 453-458.

van der Wel, R. P., & Rosenbaum, D. A. (2010). Bimanual grasp planning reflects changing rather than fixed constraint dominance. *Experimental brain research*, *205*(3), 351-362.

Weigelt, M., Kunde, W., & Prinz, W. (2006). End-state comfort in bimanual object manipulation. *Experimental Psychology*, *53*(2), 143.