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The Embodied Causal Learner

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By

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with a Concentration in Behavioral Neuroscience

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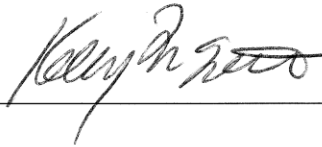
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Master's Candidate, Vanja Vlajnic, has successfully defended and made the required modifications to the text of the master's thesis for the **M.S.** during this **Fall Semester 2015.**

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Table of Contents

List of Tables

List of Figures

Abstract

Traditionally, cognitive psychology has assumed a disembodied learner and thinker. However, an emerging approach known as embodiment posits that seemingly irrelevant motor or perceptual aspects of a task can affect higher-level cognition. The findings from such embodiment studies have also been shown to extend into real-world settings. For example, children who were taught mathematical concepts while required to make gestures consistent with the problem's solution were more likely, on average, to apply the mathematical concepts correctly in the future (Cook, Mitchell, & Goldin-Meadow, 2008). For this specific study, the area of causal learning was examined.

The primary goal of this specific study was to investigate whether elements of embodiment, and any mechanisms therein, would be found in the area of causal learning. That is, would motor actions irrelevant to determining causal relationships affect an individual's causal learning? In a paradigm similar to that of Goedert and Spellman (2005), participants learned about the effects of different liquids on plant blooming on a trial-by-trial basis. Two separate liquids were used with differing causal power values, one a non-causal condition in which there was no relation between the liquid being used and plant blooming and one in which the use of the liquid was associated with a small increase in plant blooming. During the experiment, participants saw a liquid being applied to the plant or not (i.e., cause present vs. absent). In half of the conditions the cause-effect relation proceeded from left to right (cause → effect) with a liquid shown on the left side of the computer screen, pouring onto a plant on the right and during the other half of the conditions the cause-effect relation was reversed (effect ← cause). Participants then made a prediction as to whether the plant would bloom and received feedback as to

1

whether the plant bloomed. At the end of the series of trials, they made a causal judgment regarding how effective they believed the liquid was in causing plant blooming. In order to assess embodiment effects, participants were randomly sorted into one of three movement conditions in which they moved marbles left-to-right, right-to-left, or performed no movements at all. Participants in the movement condition performed the movements throughout the experiment. A secondary goal of the experiment was to determine the mechanism of any observed embodiment effects by assessing reaction time and eye-movements. An issue with microphone sensitivity rendered reaction times unmeasurable, however, eye-movements were able to be analyzed.

Because of an order effect in the causal ratings, I analyzed the causal ratings participants performed first, but did not find an effect of embodiment. The data did not support the hypotheses and an effect of contingency was not found; furthermore, the contingency effect trended in the direction opposite the hypothesis. However, eye tracking data revealed a significant interaction of place fixation by trial type, suggesting participants spent more time looking at goal-oriented directions. This study serves as a preliminary examination of embodiment in causal learning and suggests that a refinement of the methodologies used is necessary.

Keywords: causal learning, embodiment, eye-tracking, causal power

General Introduction

Cognitive psychology is primarily focused on the study of mental processes occurring within the mind (Pylyshyn, 1984; Uttal, 2003). Traditionally, cognitive psychology assumes humans to be information processors and under this view, sensory information is first translated into a symbolic representation that the mind can then process (Newell, 1994; see Figure 1 below). Cognitive psychology attempts to understand the nature of these symbolic representations and the cognitive processes that operate on them (Pylyshyn, 1984; Uttal, 2003).
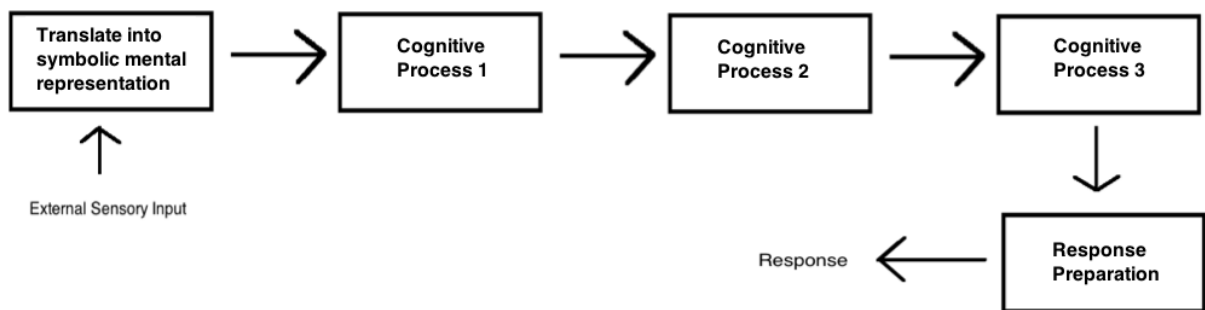
Figure 1. Example of box-and-arrow diagram of information processing

The traditional cognitive approach is exemplified in a box-and-arrow model describing the stages of information processing (Sternberg, 1969; see Figure 1 above). In the simplified model above, an external sensory input is translated into a mental representation and passed through several modules that each function separately in processing the information. Each module receives its input, completes its function, and passes along its output as the input to the next module. For example, assume someone is

3

asked for his or her age. Following from the box-and-arrow model above, the question itself would represent the external sensory input, which is translated into a symbolic mental representation so that the mind could begin to process it. The next step would include a retrieval of necessary information from long-term memory with regard to what the correct age, which may then be followed by a decision-making process as to how to respond (e.g., verbally or by showing one's age with one's hands). After the decision to verbalize the response is made, the result would enter the response preparation module, which would then lead to the final verbal response.

Each of the boxes in the box-and-arrow diagram above are considered modules, areas separate from one another that cannot influence each other's processing (e.g., Fodor, 1983; Pylyshyn, 1984; Uttal, 2003). It is important to note that only the initial sensory input is external, with the following translation of the input and cognitive processes all occurring within the mind. From this perspective, there is no reason for seemingly irrelevant aspects of perceptual characteristics and motor demands of a task to influence processes operating on these symbolic mental representations. Admittedly, this serial view of processing is an oversimplified depiction of how the mind works and many models of cognitive processing posit a more parallel and interconnected processing (for a review see Thomas & McClelland, 2008). However, even more parallel and interconnected models have generally ignored motor and perceptual influences on higher-level cognition (c.f., Barsalou et al., 2003). An emerging body of literature, however, demonstrates that irrelevant perceptual and motor aspects of a task do influence higher-level cognition (e.g., Anderson et al., 2012; Hegarty, 2004; Martin, 2007; Thomas & Lleras, 2009).

4

Irrelevant Perceptual and Motor Characteristics Affect Cognition

An alternative framework to traditional cognitive psychology that has emerged in the last 15 to 20 years is an embodied cognition approach (for a review see Davis & Markman, 2012). From an embodiment perspective, seemingly irrelevant perceptual and motor aspects of a task *can* in fact influence cognition because many cognitive processes are rooted within the body's interactions with its environment (Anderson et al., 2012; Hegarty, 2004; Martin, 2007; Thomas & Lleras, 2009). The framework suggests that these associations between the body, action, and environment are much more interconnected and fluid than traditionally thought (Anderson et al., 2012; Hegarty, 2004; Martin, 2007; Thomas & Lleras, 2009; see Smith & Sheya, 2010, for a discussion of this theoretical shift).

In one demonstration of irrelevant perceptual characteristics on mathematical reasoning, participants judged the validity of algebraic equations (Landy & Goldstone, 2007). The researchers constructed mathematical and non-mathematical permutations of equations. The mathematical permutations changed the result of the equation due to the order for operations. For example some participants saw the following:

(1) 3+2 * 4+1 = 12   or   (2) 2+3 * 1+4 = 9

In the example above, equations 1 and 2 would have different results because of the order of operations. Critically, some permutations were spatial in nature rather than mathematical. For example, some participants saw the following permutations that preserved the order of operations, but varied in the spacing of the elements:

(3) 3 + 2*4 + 1 = 12   or   (4) 3+2 * 4+1 = 12

5

In the example above, both equations 3 and 4 would have the same result, however, equation 4 makes it more difficult to follow the order of operations based on the spatial layout of the equation. In the experiment, participants saw one equation at a time, with a result, and judged whether it was correct. Despite the overall irrelevance of these non-mathematical groupings, on average accuracy was highest when the non-mathematical grouping (i.e., spatial layout) supported the mathematical grouping (i.e., order of operations; Landy & Goldstone, 2007). This finding suggests that the perceptual layout of a problem can positively or negatively influence mathematical performance.

While Landy and Goldstone (2007) evaluated perceptual influences on higher level cognition, other methodological paradigms elucidate the effects that motor actions have on higher-level cognition. In one such paradigm, participants moved marbles up and down while engaged in memory retrieval tasks (Casasanto & Dijkstra, 2010). During the experiment, participants recalled negative, neutral, or positive memories. On average, memory retrieval was faster when the direction of marble motion was congruent with the valence of the memory—that is, upward movement led to faster retrieval of positive memories and downward movement led to faster retrieval of negative memories. When prompted with valence-neutral cues, on average, participants retrieved more positive memories when moving marbles up and more negative memories when moving them down. Thus, a simple motor task influenced people's ability to recall memories with a specific valence (Casasanto & Dijkstra, 2010).

The same marble moving paradigm was utilized in demonstrating the relationship between abstract words and motor actions (Casasanto & Lozano, 2007). Participants recited stories that had either metaphorical spatial content (e.g., "my grades got *better*")

or literal spatial content (e.g., "the temperature went *up*") while moving marbles in specified directions (i.e., up, down, right, left). Participants' audio recordings were examined for instances of verbal disfluency, defined as a clause containing cases of repeats, fillers, repairs, or insertions. Disfluencies occurred in less than 1% of the uttered clauses in trials in which there were schema-congruent marble movements (e.g., upward movement during, "my grades got better"), as compared to 62% of uttered clauses during trials in which there were schema-incongruent marble movements. A similar effect was seen when participants were told to move marbles and read abstract words that had spatial components. Marble movement was fastest when the direction of movement was congruent with the implied spatial direction of the word (e.g., upward movement for *genius*, downward movement for *gloomy*). These findings are examples of the motor-meaning congruity effect, in which motor representations help represent abstract concepts beyond the role of a purely conceptual or linguistic representation (Casasanto & Lozano, 2007).

Other methodologies have also been used to examine the effects of embodiment on higher-level cognition. For example, in one experiment, participants were presented with a difficult problem-solving task while their eye movements were continuously monitored (Thomas & Lleras, 2007). Occasionally, their eye movements would be guided, via a separate visual-tracking task, in either a pattern related to the problem's solution or an unrelated pattern. Participants reported that they were unaware of any relationship between the separate tracking task and the problem-solving task. However, those who received visual guidance consistent with the problem's solution were more likely to solve the problem (Thomas & Lleras, 2007). Similar effects have been observed

7

for guided hand movements (Thomas & Lleras, 2009). Thus, these seemingly unrelated guided eye and hand movements positively affect the higher-cognitive problem-solving abilities of participants.

These effects of motor movements extend to real-world education settings. For example, in one experiment (Cook, Mitchell, & Goldin-Meadow, 2008), children were taught new mathematical concepts and during learning were required to either make gestures consistent with the problem's solution or no gesture at all. When given an assessment afterwards, children in the gesturing group were, on average, more likely to apply the mathematical knowledge correctly. Thus motor movements have the potential to improve mathematical reasoning (Cook, et al., 2008).

Why might embodiment affect higher-level cognition?

There are several hypotheses regarding why embodiment affects higher-order cognition. Barsalou and colleagues (2003) argued that congruency between cognitive tasks and perceptual and motor states leads to more effective stimulus processing, which results in the task requiring fewer processing resources. More specifically, Thomas (2013) suggested that motor movements congruent with the correct solution in a cognitive problem free up spatial working memory resources. As previously discussed, having participants move their eyes in a pattern consistent with a problem's solution increases the odds of solving that problem (Thomas & Lleras, 2007). However, this facilitative effect disappears when participants simultaneously perform a spatial working memory task, but not when they simultaneously perform a verbal working memory task (Thomas, 2013). This result suggests that if spatial working memory is somehow overloaded, it will hinder the embodied representations from facilitating problem-solving

8

(Thomas, 2013). Thus, spatial working memory may mediate the facilitative effects of action on problem-solving.

A second possibility is that embodiment effects result from changes in how an individual directs his or her attention. Evidence for this idea comes from experiments showing that greater attention is allocated to space near the hands (Reed, et al., 2006; see also Baldaur & Deubel, 2008; Festman, et al., 2013). It seems to be the case that more attention is allocated toward the hands because the hands are the primary tools with which we interact with our environment (Reed, Grubb, & Steele, 2006). These effects of movement and hand location may be a mechanism for the effects of guided eye and hand movement on problem-solving (Thomas & Lleras, 2007, 2009). The guided movements of the eyes and hands may facilitate attention to the correct solutions of the problem (Baldauf & Deubel, 2008; Festman et al., 2013; Reed, et al., 2006; Thomas & Lleras, 2007; 2009).

Freed-up working memory resources, congruent representational states, and changes in the distribution of attention all refer to potential cognitive mediators of perceptual and motor effects on higher-level cognition. What neural mechanisms might underlie these cognitive effects? Seemingly irrelevant aspects of perceptual and motor tasks may affect higher-level cognition because of shared neural resources (Anderson et al., 2012; Chafee & Crowe, 2013). Anderson, and colleagues (2012) put forth an evolutionary argument that basic motor and perceptual processes, which emerged earlier in our evolutionary history, have dedicated neural architecture. However, higher-level cognitive functions, which evolved later, were laid upon this existing neural architecture. Evidence for this idea comes from studies demonstrating the recruitment of areas of the

motor cortex for higher-level cognitive tasks. For example, both the manipulation of physical objects with the hands and reading comprehension recruit similar cortical areas (Goldin-Meadow & Beilock, 2010).

Chafee and Crowe (2013) articulate a specific theory of shared neural resources for spatial representation in the parietal cortex and review evidence for an overlapping hierarchy of spatial representations. This hierarchy spans from sensorimotor signals highly related to stimuli or movements, to sensorimotor signals modified to facilitate cognitive processes (such as those found in decision processing and working memory), and finally to the representation of abstract spatial information independent of sensorimotor signals. According to this view, the higher-level cognitive signals stem from and are built upon lower-level sensorimotor signals (Chafee & Crowe, 2013).

It is important to note that the above theories may not be inconsistent with one another. Instead, it might be the case that these embodiment effects are due to an interaction of all of these mechanisms. More specifically, embodiment effects may be due to the freeing up of working memory (Thomas, 2013) and a preferential allocation of attention (Festman et al., 2013; Baldauf & Deubel, 2008; Reed, Grubb, & Steele, 2006; Thomas Lleras, 2007; 2009), with these cognitive effects mediated by shared neural resources (Anderson et al., 2012; Chafee & Crowe, 2013).

Embodiment and Causal Learning

Even though there have been demonstrated effects of embodiment on several higher-level cognitive processes, as well as some theories as to why we might expect to see such effects, many research areas prominent in traditional cognitive psychology have yet to be assessed from an embodied perspective. One such area is causal learning, which

10

looks at how people learn the relationship between cause and effect. For example, suppose a hunter-gatherer society is going through an arduous famine. A woman of the group decides to quell her hunger by eating a handful of red berries found on a local bush, only to suddenly die a day later. It is imperative for the rest of the group's members to learn from this mistake and not to repeat it in order to ensure the survival and success of their society (Rutter, 2007; Allan, 1980).

When assessing causal relationships from contingency information, it is often helpful to refer to a contingency table (Table 1). The contingency table has four separate cells. Cell A corresponds to the number of times when the cause and effect are both present. For example, if we consider how often death occurs (the effect) after consumption of the red berries (the cause), the value would be represented in Cell A of Table 1. Cell B represents when the cause is present and the effect is absent; cell C corresponds to when the cause is absent and the effect is present; cell D represents when both the cause and outcome are absent. By using the frequency of events in each of the cells of the contingency table, we can calculate the contingency between eating the red berry and death. The value of all the cells in Table 1 must be known in order to correctly calculate the contingency between these binary events (Allan, 1980). However, when asked to examine plausible causes, people often put greatest weight on information in Cell A of the contingency table (Mandel & Lehman, 1998).

Table 1

2x2 Contingency Table

	Effect Present	Effect Absent
Cause Present	A	B
Cause Absent	C	D

Although there are many ways in which the frequency information from Table 1 might be combined to assess the contingency – and subsequently, the causal relationship – between two events (e.g., Hattori & Oaksford, 2007), the theoretical approach dominating recent work in the area of causal learning is Cheng's (1997) Causal Power Theory.[1] In order to understand causal power, one must first understand Allan's (1980) delta P:

Equation 1.

$$\Delta P = P(E|C) - P(E|\neg C)$$

In the above equation, $P(E|C)$ represents the probability (P) of the effect (E), given the cause (|C), and $P(E|\neg C)$ represents the probability (P) of the effect (E), given that the cause is absent ($|\neg C$). An effect is dependent on the cause if the probability of the effect given the cause is larger than the probability of the effect in the absence of the

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[1] Bayesian models can be used to assess how people make inferences about systems of causal relationships (Griffiths & Tennenbaum, 2001). Because Cheng's (1997) causal power can be a point estimate of Griffiths & Tenenbaum's (2001) causal strength, I will be using causal power as the normative standard regarding how people should both use and combine frequency information.

12

cause. This is also known as a facilitative or a generative cause. Similarly, a preventive or an inhibitory cause is one in which the probability of the effect is greater when the cause is absent than when it is present (i.e., the value of ΔP is negative; Cheng, 1997).

Cheng's (1997) power PC model expands upon Allan's (ΔP) by going beyond pure covariation to an estimate of *causal power*, which can be estimated from covariation by dividing ΔP by one minus the base rate occurrence of the outcome. Generative causal power (p) is represented mathematically (Cheng, 1997) as:

Equation 2.

$$p = \frac{P(E|C) - P(E|\neg C)}{1 - P(E|\neg C)}$$

Even though effects of embodiment have been found in various areas of cognition (for a review, see Anderson et al., 2012), to date, no one has examined whether such effects are present in causal learning. Theories of causal learning from contingency, including Cheng's normative (1997) causal power theory, do not predict effects of embodiment. Specifically, no one has assessed whether simple movements, irrelevant to the task, can influence our ability to detect causal relationships.

Current Study

The primary goal of the present study was to determine whether motor actions irrelevant to determining causal relationships affect causal learning. A secondary goal of the experiment was to determine the mechanism of any observed embodiment effects by assessing reaction time and eye-movements. In a paradigm similar to that of Goedert & Spellman (2005), participants learned about the effects of different liquids on plant blooming on a trial-by-trial basis. On each trial, participants viewed an event representing one of the cells of the 2x2 contingency table (Table 1): They saw a liquid being applied to

the plant or not (i.e., cause present vs. absent). They then made a prediction as to whether the plant would bloom and received feedback as to whether the plant bloomed. Over a series of trials, they received the complete frequency information from the 2x2 contingency table. At the end of the series of trials, they made a causal judgment regarding how effective they believed the liquid was in causing plant blooming.

Both the direction of the cause-effect relationship and the direction of motor actions were manipulated in the experiment. The direction of the cause-effect relationship was manipulated within-subjects (see Figure 2 below). In one condition the cause-effect relation proceeded from left to right (cause → effect): a liquid appeared on the left side of the computer screen, pouring onto a plant on the right. In a second condition the cause-effect relation proceeded from right to left (effect ← cause): a liquid appeared on the right side of the computer screen, pouring onto a plant on the left.

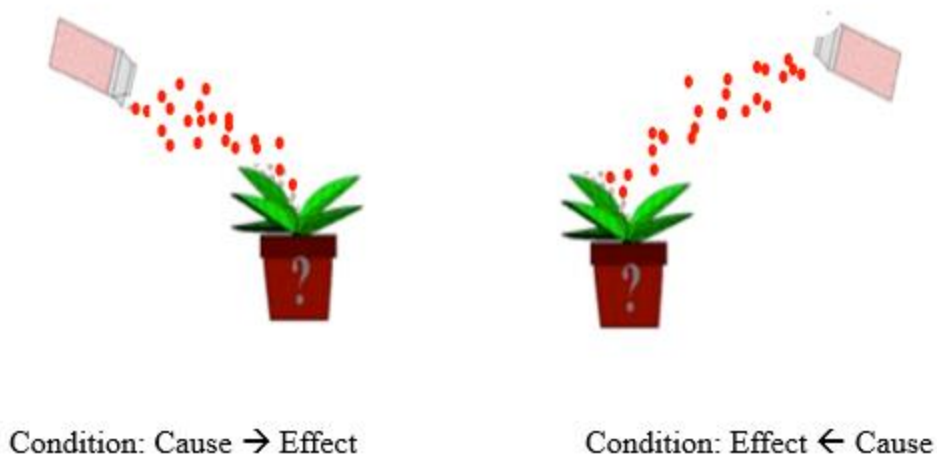Condition: Cause → Effect   Condition: Effect ← Cause

Figure 2. Two directions of causal elements presented

During the trials, participants made irrelevant motor movements that were either congruent or incongruent with the direction of the cause and effect variables by moving marbles either left to right or right to left (after Casasanto & Djikstra, 2010; Casasanto &

14

Lozano, 2007). These manipulations produced two conditions in which the irrelevant motor movements were congruent with the causal direction and two in which they were incongruent (Table 2). Additionally, a control condition without movement was included as an assessment for baseline causal learning without motor action. I predicted that movements congruent with the causal direction would facilitate causal learning and that movements incongruent with the causal direction would hinder causal learning.

Table 2

Congruent and incongruent conditions found in the task.

Marble Movement	Causal Direction Cause → Effect	Causal Direction Effect ← Cause
Left → Right	Congruent	Incongruent
Right ← Left	Incongruent	Congruent

In order to test causal learning, I used two contingency conditions. Tables 3 and 4 below depict the contingency tables for the two contingency conditions. The causal power of the first condition was 0, denoting a non-contingent condition in which there is no relation between the liquid being used and plant blooming. The causal power of the second condition was 0.25, denoting a contingent condition in which the use of the liquid was associated with a small increase in plant blooming.

Table 3

2x2 Contingency Table for the 0 Causal Power Condition

	Effect Present	Effect Absent
Cause Present	6	3
Cause Absent	2	1

15

Table 4

2x2 Contingency Table for the 0.25 Causal Power Condition

	Effect Present	Effect Absent
Cause Present	5	3
Cause Absent	2	2

These contingency values were chosen based on data showing that participants correctly discriminated between them 30% of the time (Allan et al., 2008). Thus, the contingencies were discriminable, but it was a relatively difficult discrimination, which should prevent floor or ceiling effects. The key prediction was that participants' ability to discriminate between these two contingency conditions would be facilitated by movements congruent with the causal direction and potentially hurt by movements incongruent with the causal direction.

Method

Participants

In order to determine the number of participants needed for this study, an *a priori* power analysis was performed to estimate the sample size needed to detect the between-within interaction in a 2 x 2 x 3 mixed ANOVA using G*Power 3.1.7 (Buchner et al., 2009). No published studies had examined this exact interaction and thus I powered a small-to-medium effect ($\eta_p^2 = 0.03$) for the interaction, with a correlation among repeated measures of 0.36 (based on previous causal learning studies in Dr. Goedert's laboratory). The *a priori* power analysis revealed that a total sample size of 75 participants would be necessary to achieve 80% power at an α of 0.05.

Eighty-four undergraduate students (24 men; 60 women) from Seton Hall University's Department of Psychology participant pool took part in the experiment either to fulfill a course requirement or for extra credit. All participants provided written informed consent. Because handedness may affect embodiment (e.g., Casasanto, 2009), only individuals scoring as right-handed were allowed to participate. Participants completed a prescreening survey and only right-handed participants (scoring above a 0 on the revised Edinburgh Handedness Inventory; see Dragovic, 2004 for the exact scale and see Appendix A for its psychometric properties) were allowed to take part in the study.

Design

The experiment was a 2 (causal direction: left-to-right, right-to-left) X 2 (contingency: 0.00, 0.25) X 3 (movement direction: left-to-right, right-to-left, none) X 4 (order) mixed factorial design. The direction of causal elements and contingency were within-groups factors while movement direction and order were between-groups factors.

17

The order variable reflected a Latin-square counterbalancing of the within-group conditions.

Materials

Participants sat in front of a computer for the duration of the experiment. A microphone and two boxes, one full with marbles and one empty, were placed in front of the participants. All stimuli were presented and behavioral responses collected using the computer program E-Prime (Schneider, Eschman, & Zuccolotto, 2002). A Tobii X120 eye-tracker, mounted below the computer screen, tracked participants' eye movements throughout the entire experiment at a rate of 60 Hz.

Procedure

Causal Learning Task. The causal cover story asked the participant to imagine cleaning out his or her garage and finding unlabeled containers with liquids in them. The participant's task was to determine whether or not the liquids had an effect on plant growth (see Appendix B for complete cover story; Goedert & Spellman, 2005). Participants saw each contingency value (0.00, 0.25) twice, once with each casual direction (0.00 with cause → effect; 0.00 with effect ← cause; 0.25 with cause → effect 0.25 with effect ← cause). This resulted in a total of four blocks of 12 trials each with a different colored liquid used for each block of trials.
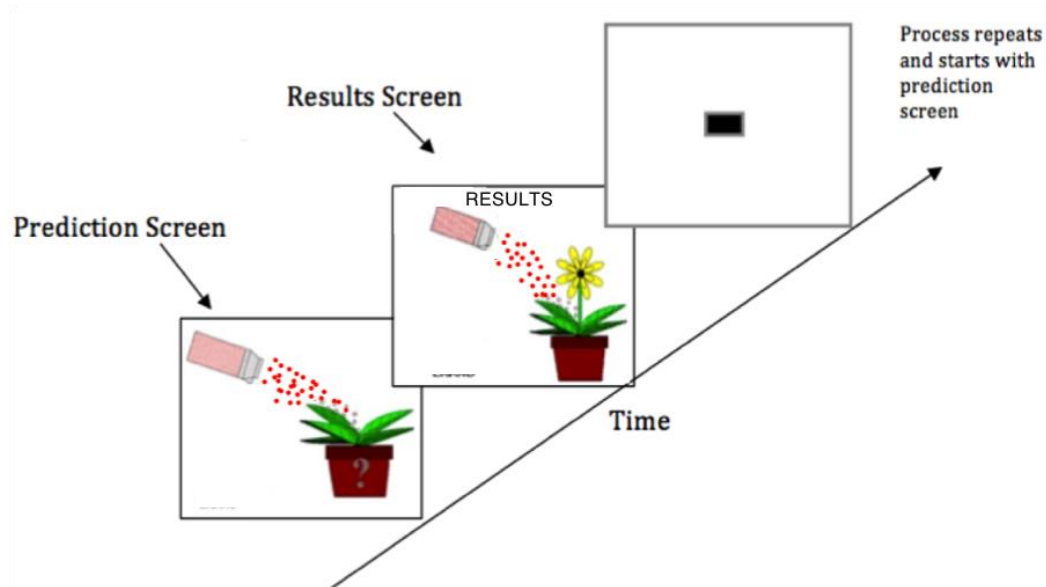
Figure 3. A sample trial from the contingency task, separated by a fixation screen.

A visual depiction of the task can be seen in Figure 3. The participant saw a prediction screen showing the liquid (the cause) either being poured onto the plant (the effect) or not. The participant then predicted whether the plant would bloom by saying "*yes*", indicating that the plant will bloom, or "*no*" indicating that the plant would not bloom, directly into a microphone attached to an E-Prime stimulus response box. When the participant vocalized a response, it triggered the end of the prediction screen and E-Prime recorded the reaction time (Schneider, Eschman, & Zuccolotto, 2002). Simultaneously, the experimenter, seated behind the participant, recorded the participant's response using a wireless keyboard. After vocalizing his or her response, the participant received feedback as to whether or not the plant bloomed (1000 ms). After each block of trials, participants rated how effective the liquid was in producing plant blooming on a scale from 0 to 100 by vocalizing their responses (see Appendix C for actual scale), with 0 representing the liquid had no effect on plant growth and 100

19

representing the liquid always caused plant growth. Participants could use any number in between if they thought the liquid had some effect, but did not always cause, plant blooming.

Marble-Moving Task. While performing the causal learning task, participants also performed a variation of the marble-moving task (Casasanto & Djikstra, 2010; Casasanto & Lozano, 2007). An example of the setup and movement for an observer in the left-to-right movement condition can be seen in Figure 4 below. The right-to-left movement condition would be the exact reverse of what is shown in Figure 4. Seated in front of the computer monitor, participants found two boxes on either side of them; one was filled with marbles. Because word cues indicating spatial locations produce shifts of attention that can impact reaction time (Dudschig et al., 2013), marble boxes were referred to by color (white/black) instead of spatial locations (left/right). Participants in the movement condition moved one marble in each hand from the starting box (the box with the marbles) to the destination box (the box with no marbles) to the sound of a metronome. The metronome sounded at 30 beats-per-minute, which resulted in the movement of 30 marbles with each hand per minute. This timing was chosen based on pilot testing indicating that this was the fastest speed at which participants could move the marbles and still pay attention to the causal learning task. In the no movement condition, the participant's hands remained stationary and thus there was no direction of marble movement and instead only the direction of causal elements varied.
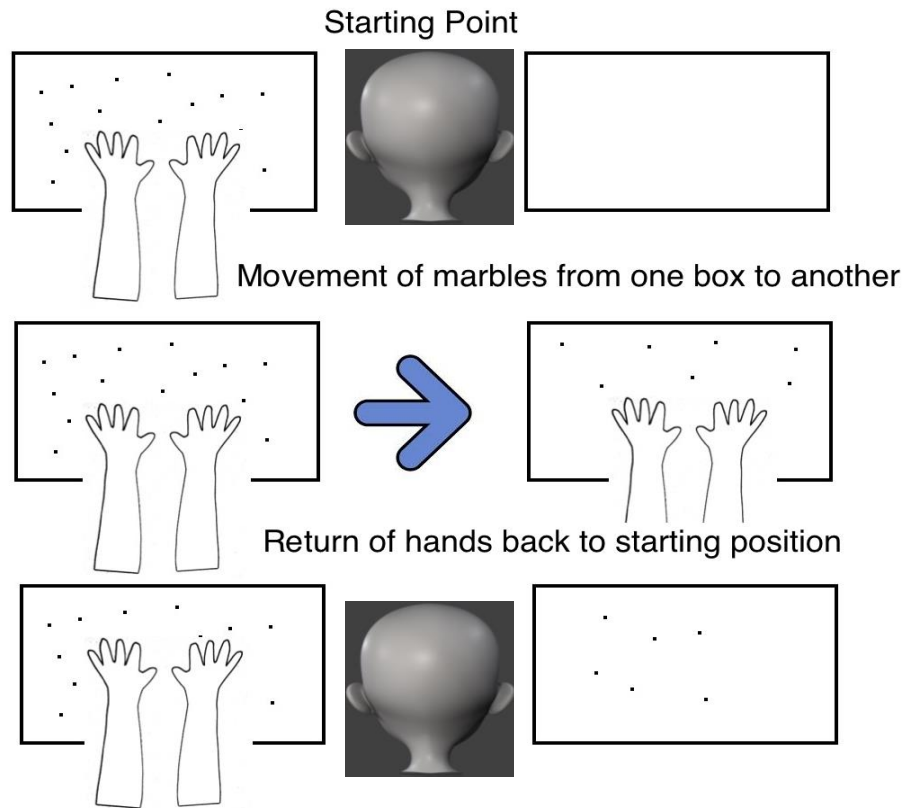
Figure 4. Depiction of marble movement paradigm from left-to-right used in the task.

Experimental Trials. Participants began with six practice trials using a different colored liquid to familiarize them with simultaneously performing the marble moving and contingency learning task. The practice trials used a causal power ($p = 0.50$), which is different from the causal power used in the actual experiment ($p = 0.00$, $p = 0.25$). After the practice trials were completed, the participants began with the experimental conditions. Prior to the beginning of each block of experimental trials, participants in the movement conditions transferred marbles for 30 seconds to re-acclimate to the marble moving task and continued the movements through the prediction screens.

21

Embodiment in Causal Judgments?

The primary dependent measure for detecting embodiment in causal learning was the
participants' causal ratings of the four liquids.

Preliminary analyses revealed significant order effects. The 2 (causal direction) x
3 (movement direction) x 2 (contingency) x 4 (order) mixed ANOVA yielded an
interaction between contingency, causal direction, and order, $F(3,72) = 3.31$, $p = 0.024$,
$\eta_p^2 = 0.12$, and no other effects, all $ps > 0.12$ (See Appendix C for complete statistics on
nonsignificant effects). While every effort was made to interpret the order effects, this
interaction was not clearly interpretable. Full details of the order analyses are presented in
Appendix C. Because of the effect of order, further analyses were computed using only
the condition that participants completed first, essentially treating the data as a fully
between-groups experiment.

Figure 5 depicts the means of participants' first ratings by contingency and
movement congruency, with the congruent condition representing participants' ratings
when the direction of marble movement and causal elements matched up and the
incongruent condition representing participants' ratings when the direction of marble
movement and causal elements differed. It was hypothesized that participants' causal
ratings would be least accurate in the incongruent condition and most accurate in the
congruent condition, with the no movement condition serving as a baseline control
condition for the causal ratings. Specifically, it was hypothesized that participants would
rate the 0 causal power condition closer to 0 and the 0.25 causal power condition closer
to 0.25 in the congruent condition. In the incongruent condition, it was expected that the

participants would not discriminate between the 0 and 0.25 contingency, rating them closer together. However, the actual results did not align with the hypothesized results. Table 5 depicts the means of the first ratings and standard deviations by cause direction and movement.

The 2 (contingency) x 2 (causal direction) x 3 (movement direction) between groups ANOVA yielded no significant effects (all ps > 0.238; See Appendix D for complete statistics on nonsignificant effects). Specifically, the predicted interaction between contingency, causal direction, and movement condition was non-significant, F (2,72) = 0.11, p = 0.893, η_p^2 = 0.01. From Figure 5, we see that the means across conditions are almost identical. There is no difference among the causal ratings in each subgroup (congruent, incongruent, no movement), suggesting that the embodiment manipulation did not work. Even though the main effect of contingency did not reach significance (F (1,72) = 1.42, p = 0.238, η_p^2 = 0.02), we can see that participants' mean causal ratings were trending in the opposite direction of those predicted, with participants rating the zero causal power condition as higher, on average, than the 0.25 causal power condition. This result suggests that the contingency manipulation did not work either.
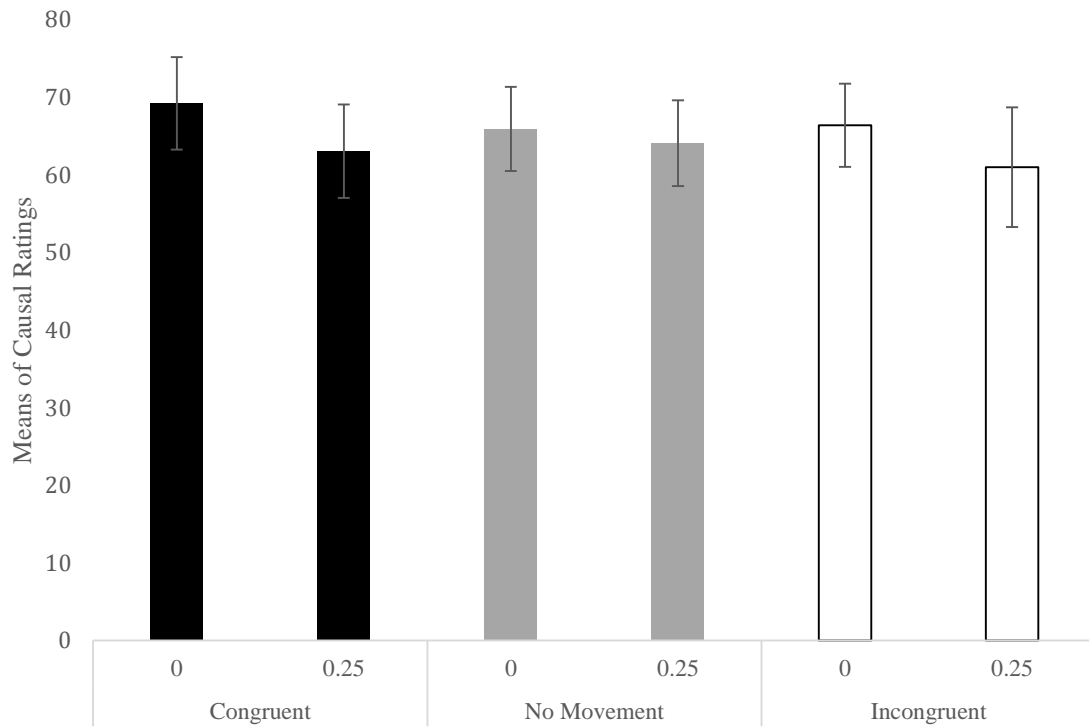
23

Figure 5. Means of causal ratings by contingency and movement direction. Error bars indicate standard error of the mean.

Table 5

Means of first ratings by movement condition (Left-to-Right, Right-to-Left, No Movement), causal direction, and contingency (p=0, p = 0.25)

Condition	Contingency	Cause Direction	
		R -> L	L -> R
Left-to-Right	p = 0	68.5714 (8.52)	66.11 (20.28)
	p = 0.25	65.43 (11.75)	64.17 (18.55)
Right-to-Left	p = 0	76.25 (10.31)	64.90 (23.81)
	p = 0.25	62.14 (11.85)	55.83 (26.91)
No Movement	p = 0	61.5 (26.146)	70.4 (27.72)
	p = 0.25	65.33 (21.09)	62.86 (11.13)

Note. Standard deviations in parentheses.

24

A potential explanation for the difficult to interpret behavioral results is the outcome density effect. According to the outcome density effect, an individual judges a relationship as more causal when the frequency of the effect is higher (Allan, Siegel, & Tangen, 2005). Referencing Tables 3 and 4 above, we can see that the 0 contingency condition, a *non-causal* condition, had a higher base rate of the outcome (8) than that of the *causal* 0.25 contingency condition (7). This could be a potential reason as to why the causal ratings for the 0 contingency condition were higher across all groups as compared to the 0.25 contingency condition and thus the outcome density effect could potentially be a key component causing the uninterpretable results in the behavioral data.

Exploring Mechanisms of Embodiment Effects

Even though no effects of embodiment were observed in the behavioral data, reaction time and eye movement data could still provide insight into potential underlying mechanisms of embodiment. However, an issue with the microphone's sensitivity to end a trial when a participant vocalized his/her response led to the inability of RT data to be used for analysis; therefore, only the eye-tracking data could be analyzed.

Eye-Tracking Data Pre-Processing

The eye-tracking dependent measure were the time participants spent viewing each side of the screen during prediction screen trials, which was broken down by trial in order to compare whether the participants were spending more time looking at the cause (the liquid) or the effect (the plant) variable. Only eye movements during the prediction screens were analyzed because they were the only screens in the experiment that contained solely pictures without any words. This was important as words could induce a left-to-right reading bias (Casasanto, 2009) and would thus affect the overall proportion of time spent viewing either side of the screen.

25

The eye-tracking data were cleaned prior to analysis. Individual trials were eliminated under two scenarios: 1) if the prediction RT was less than 250 ms because this is too early in the trial for semantic processing to have been executed (Eberhard et al., 1995), and 2) if the RT was more than 2.5 standard deviations from the mean RT for participants in that condition.

Within the eye tracking data, a multilevel mixed-effects linear regression was performed modelling participant intercepts as the random effect. There was a significant interaction of causal direction of elements and place fixation (F (1,167) = 4.37, p = 0.038, Cohen's d = 0.02), with participants spending more time fixating on the goal/effect variable (the plant; M = 1580.59, SD = 1836.09) than on the cause variable (the liquid; M = 707.52, SD = 1847.95). This interaction is depicted in Figure 6 below. When the causal direction of elements went from left to right, the participants fixated longer on the plant located on the right side. Similarly, when the causal direction of elements went from right to left, the participants fixated longer on the plant located on the left side. This finding is supported by the literature showing that individuals allocate more time to the side of visual space where the effect variable is located (Grant & Spivey, 2003; Thomas & Lleras, 2007; 2009).
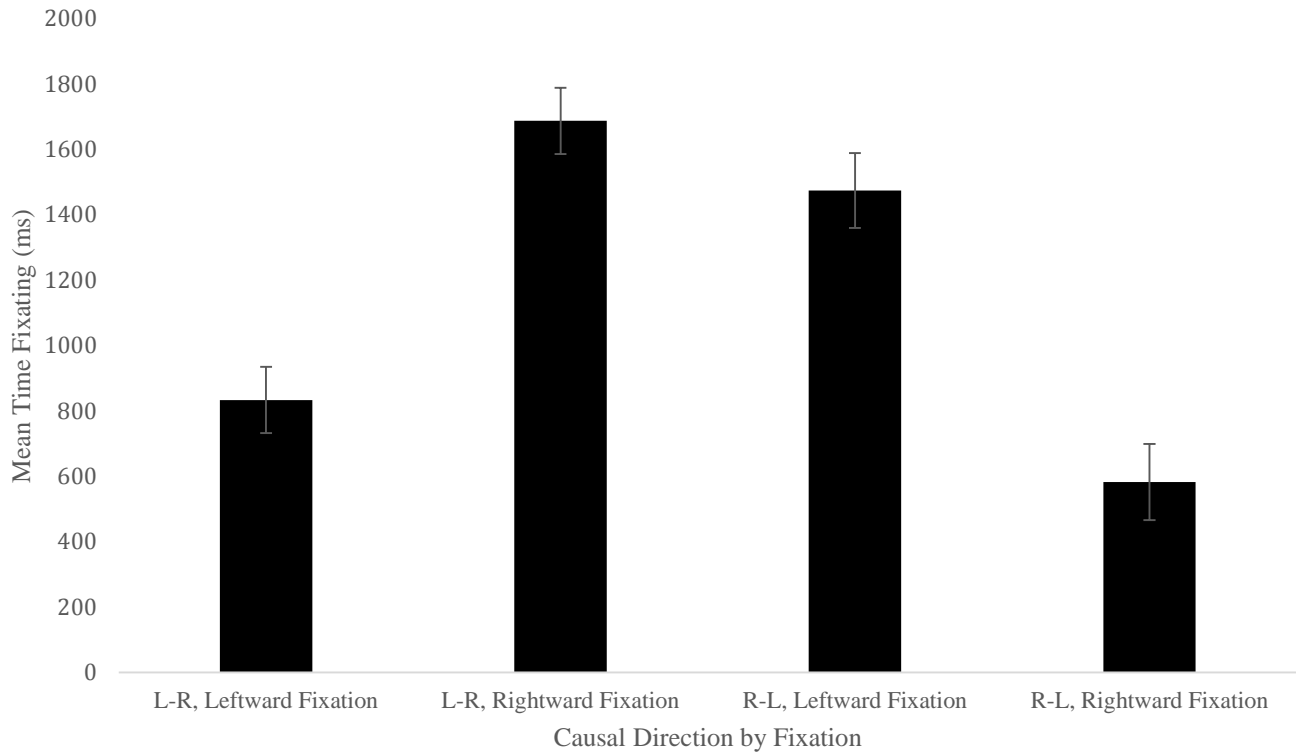
Figure 6. Means of time spent fixating (ms) in the interaction of causal direction of elements and place fixation. Error bars depict standard errors.

There was also a significant interaction of place fixation by trial type ($F(1,167) = 3.93$, $p = 0.049$, Cohen's $d = -0.01$), irrespective of causal direction or movement condition, participants spent more time fixating on the right half of the screen when the cause was present ($M = 1196.68$, $SD = 1594.60$) and more time fixating on the left half of the screen when the cause was absent ($M = 1255.78$, $SD = 1585.87$). Lastly, there was a significant effect of place fixation ($F(1,167) = 11.82$, $p = 0.001$, Cohen's $d = -0.03$), with participants spending more time fixating on the right side of the screen ($M = 1195.51$, $SD = 1771.01$) than on the left half ($M = 1148.22$, $SD = 1772.14$). A potential reason for this could be due to our left-to-right reading convention; however, there were no words on the screen during the trials in which eye movements were recorded. Nevertheless, even in a picture book, one might expect individuals who speak languages in which reading flows from left-to-right to "read" the pictures from left-to-right and therefore spend a longer

27

time fixating on the right half of the screen. Nevertheless, the relevancy of this effect to the current study is minimal and a revised methodology is necessary to explore it in further detail.

The main predicted interaction between movement condition, causal direction of elements, and place fixation was non-significant ($F (1,72) = 1.54$, $p = 0.218$, $\eta_p^2 = 0.06$). Table 6 below depicts the mean time spent fixating (ms) by movement condition and causal direction of elements. No other effects or interactions reached significance (all ps > 0.058).

Table 6

Means of time (ms) spent fixating (Leftward, Rightward) by movement condition (Left to Right, Right to Left, No Movement) and causal direction (L->R, R-> L).

Cause Direction	Fixation	Left-to-Right	Right-to-Left	No Movement
L -> R	Leftward	827.22 (1836.01)	962.06 (1621.77)	701.82 (1662.00)
L -> R	Rightward	1685.81 (1836.01)	1690.75 (1621.77)	1651.24 (1673.27)
R -> L	Leftward	1539.84 (1742.69)	1926.94 (2030.08)	907.32 (2111.01)
R -> L	Rightward	529.67 (1734.60)	666.51 (2028.778)	543.03 (2279.76)

Note. Standard deviations in parentheses.

28

General Discussion

It was hypothesized that congruent movements of causal direction and motor action would facilitate causal learning and that incongruent movements of causal direction and motor action would hinder causal learning. However, both the behavioral data and eye tracking data failed to support this hypothesis. Specifically, in regards to the behavioral data, it was clear that certain methodological shortcomings affected the interpretability of the data. First, as had been pointed out by several of the participants in the study, the participants performed many actions simultaneously during the experiment, which may have distracted their attention away from learning about the causal relationship between the liquids and the plant. During the experiment, the participants had to focus on moving marbles and vocalizing their responses, which were plagued by issues concerning the microphone sensitivity, all while attempting to learn about the causal relationships.

Even though the behavioral data did not allow for interpretable results, the eye-tracking data hinted at some underlying embodiment effects present. Nevertheless, it is clear that changes to the methodology used in the experiment are necessary for clearer, more interpretable and generalizable results. In an attempt to correct some of these potential limitations found in the current study, a follow-up study has begun examining the same hypothesis as the current study. However, new contingency information has been chosen so that the data from the follow-up experiment are not confounded by the outcome density effect previously discussed. Specifically, in the new study, the frequency of the effect is higher in the causal contingency than in the non-causal contingency.

29

Furthermore, due to the microphone's limited sensitivity and difficulties in assessing reaction times, the use of a microphone has been removed from the follow-up experiment. Instead, participants simply vocalize their responses, which are inputted into E-Prime by the experimenter. This lets the experiment proceed without microphone issues as well as allowing for the participants to focus more of their attention on learning the causal relationships. Additionally, instead of using four different liquids, two liquids are shown twice, which permits a more direct comparison between groups. With these changes to the methodology, the follow-up experiment will be better suited to elucidate any effects in the future data, without falling victim to the outcome density effect and further uninterpretable results.

Overall, as there have been numerous accounts of embodiment effects found in a wide variety of areas (Landy & Goldstone, 2007; Anderson, et al., 2012; Hegarty, 2004; Martin, 2007; Thomas & Lleras, 2009; Casasanto & Dijkstra, 2010; Casasanto & Lozano, 2007; Lakens et al., 2011), it would be premature to discount causal learning as an area in which embodiment effects may be found due to the results of this one experiment. Rather, taken into a larger context, this experiment can serve as a preliminary experiment providing insight into what methodologies can be used to further address whether embodiment effects are truly present in causal learning.

References

Allan, L. G. (1980). A note on measurement of contingency between two binary variables in judgment tasks. *Bulletin of the Psychonomic Society, 15,* 147-149. dx.doi.org/10.3758/BF03334492

Allan, L. G., Siegel, S., & Tangen, J. M. (2005). A signal detection analysis of contingency data. *Learning & Behavior*, *33*, 250-263.

Anderson, M. L., Richardson, M. J., & Chemero, A. (2012). Eroding the boundaries of cognition: Implications of embodiment. *Topics in Cognitive Science*, *4*, 717-730. dx.doi.org/10.1111/j.1756-8765.2012.01211.x

Baldauf, D., & Deubel, H. (2008). Properties of attentional selection during the preparation of sequential saccades. *Experimental Brain Research*, *184*, 411-425. dx.doi.org/10.1007/s00221-007-1114-x

Barsalou, L. W., Kyle Simmons, W., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences*, *7*, 84-91. dx.doi.org/10.1016/S1364-6613(02)00029-3

Box, G. E. P, Hunter, WG and Hunter, JS (1978) Statistics for experimenters. *An introduction to design data analysis and model building*. John Wiley and Sons Publishing.

Buchner, A., Erdfelder, E., Faul, F., & Lang, A. (2009). G*Power (Version 3.1.7) [Computer program]. www.psycho.uni-duesseldorf.de/aap/projects/gpower/

Casasanto, D. (2009). Embodiment of abstract concepts: Good and bad in right-and left-handers. *Journal of Experimental Psychology: General*, *138,* 351. dx.doi.org/10.1037/a0015854

Casasanto, D. (2009). When is a linguistic metaphor a conceptual metaphor. *New Directions in Cognitive Linguistics*, *24*, 127. dx.doi.org/10.1075/hcp.24.11cas

31

Casasanto, D., & Dijkstra, K. (2010). Motor action and emotional memory. *Cognition*, *115*, 179-185. dx.doi.org/10.1016/j.cognition.2009.11.002

Casasanto, D., & Henetz, T. (2012). Handedness shapes children's abstract concepts. *Cognitive Science*, *36*, 359-372. dx.doi.org/10.1111/j.1551-6709.2011.01199.x

Casasanto, D., & Lozano, S. (2007). Meaning and motor action. In *Proceedings of the 29th Annual Meeting of the Cognitive Science Society* (pp. 149-154).

Chafee, M.V., Crowe, D.A. (2013). Thinking in spatial terms: Decoupling spatial representation from sensorimotor control in monkey posterior parietal areas 7a and LIP. *Frontiers in Integrative Neuroscience*, *25*. dx.doi.org/10.3389/fnint.2012.00112

Cheng, P. W. (1997). From covariation to causation: A causal power theory. *Psychological Review*, *104*, 367. dx.doi.org/10.1037/0033-295X.104.2.367

Cook, S. W., Mitchell, Z., & Goldin-Meadow, S. (2008). Gesturing makes learning last. *Cognition*, *106*, 1047-1058. dx.doi.org/10.1016/j.cognition.2007.04.010

Davis, J. I., & Markman, A. B. (2012). Embodied Cognition as a practical paradigm: Introduction to the topic, the future of embodied cognition. *Topics in Cognitive Science*, *4*, 685-691. dx.doi.org/10.1111/j.1756-8765.2012.01227.x

de la Fuente, J., Casasanto, D., & Santiago, J. (2015). Observed actions affect body-specific associations between space and valence. *Acta Psychologica*, *156*, 32-36.

Dragovic, M. (2004). Towards an improved measure of the Edinburgh Handedness Inventory: A one-factor congeneric measurement model using confirmatory factor analysis. *Laterality*, *9*, 411–419. dx.doi.org/10.1080/13576500342000248.

Dudschig, C., Souman, J., Lachmair, M., de la Vega, I., & Kaup, B. (2013). Reading "sun" and looking up: The influence of language on saccadic eye movements in the vertical dimension. *PloS one*, *8*, e56872. doi: 10.1371/journal.pone.0056872

Duncker, K., & Lees, L. S. (1945). On problem-solving. *Psychological Monographs*, *58*(5) i. dx.doi.org/10.1037/h0093599

Eberhard, K.M., Spivey-Knowlton, M.J., Sedivy, J.C., Tanenhaus, M.K. (1995). Eye movements as a window into real-time spoken language comprehension in natural context. *Journal of Psycholinguistic Research*. *24*, dx.doi.org/10.1007/BF02143160

Festman, Y., Adam, J. J., Pratt, J., & Fischer, M. H. (2013). Continuous hand movement induces a far-hand bias in attentional priority. *Attention, Perception, & Psychophysics*, *75*, 644-649. dx.doi.org/10.3758/s13414-013-0430-4

Fodor, J. A. (1983). *The modularity of mind: An essay on faculty psychology*. Cambridge, Mass.: MIT press.

Fodor, J. A., & Pylyshyn, Z. W. (1988). Connectionism and cognitive architecture: A critical analysis. *Cognition*, *28*, 3-71. dx.doi.org/10.1016/0010-0277(88)90031-5

Goedert, K. M., & Spellman, B. A. (2005). Nonnormative discounting: There is more to cue interaction effects than controlling for alternative causes. *Learning & Behavior*, *33*, 197-210. dx.doi.org/10.3758/BF03196063

Goldin-Meadow, S., & Beilock, S. L. (2010). Action's influence on thought: The case of gesture. *Perspectives on Psychological Science*, *5*, 664-674. dx.doi.org/10.1177/1745691610388764

Grant, E., & Spivey, M. (2003). Eye movements and problem solving: guiding attention guides thought. *Psychological Science*, *14, 462-466*. dx.doi.org/ 10.1111/1467-9280.02454

33

Hattori, M., & Oaksford, M. (2007). Adaptive non-interventional heuristics for covariation detection in causal induction: Model comparison and rational analysis. *Cognitive Science*, *31*, 765-814. dx.doi.org/10.1080/03640210701530755

Hegarty, M. (2004). Dynamic visualizations and learning: Getting to the difficult questions. *Learning and Instruction*, *14*, 343-351. dx.doi.org/10.1016/j.learninstruc.2004.06.007

Lakens, D., Schneider, I. K., Jostmann, N. B., & Schubert, T. W. (2011). Telling things apart: the distance between response keys influences categorization times. *Psychological science*, *22*, 887-890. dx.doi.org/10.1177/0956797611412391

Landy, D., & Goldstone, R. L. (2007). How abstract is symbolic thought?. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*, 720. dx.doi.org/10.1037/0278-7393.33.4.720

Mandel, D. R., & Lehman, D. R. (1998). Integration of contingency information in judgments of cause, covariation, and probability. *Journal of Experimental Psychology: General*, *127*, 269.

Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology*, *58*, 25-45. dx.doi.org/10.1146/annurev.psych.57.102904.190143

Newell, A. (1994). *Unified theories of cognition*. Cambridge, Mass.: Harvard University Press.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, *9*, 97-113. dx.doi.org/10.1016/0028-3932(71)90067-4

Pylyshyn, Z.W. (1984). *Computation and cognition: Towards a foundation for cognitive science.* Cambridge, Mass.: MIT Press.

Ransil, B. J., & Schachter, S. C. (1994). Test-retest reliability of the Edinburgh Handedness

Inventory and Global Handedness preference measurements, and their correlation.

Perceptual and motor skills, *79*, 1355-1372. dx.doi.org/10.2466/pms.1994.79.3.1355

Reed, C. L., Grubb, J. D., & Steele, C. (2006). Hands up: attentional prioritization of space near

the hand. *Journal of Experimental Psychology: Human Perception and Performance*, *32*,

166. dx.doi.org/10.1037/0096-1523.32.1.166

Rutter, M. (2007). Proceeding from observed correlation to causal inference: The use of natural

experiments. *Perspectives on Psychological Science*, *2*, 377-395. doi: 10.1111/j.1745-

6916.2007.00050.x.

Schneider, W., Eschmann, A., & Zuccolotto, A. (2002). E-Prime v1.1. *Pittsburgh, PA:*

Psychology Software Tools Inc.

Smith, L. B., & Sheya, A. (2010). Is cognition enough to explain cognitive development?. *Topics*

in Cognitive Science, *2*, 725-735. dx.doi.org/10.1111/j.1756-8765.2010.01091.x

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta*

Psychologica, *30*, 276-315. dx.doi.org/10.1016/0001-6918(69)90055-9

Tenenbaum, J. B., & Griffiths, T. L. (2001). Generalization, similarity, and Bayesian inference.

Behavioral and brain sciences, *24*, 629-640. dx.doi.org/10.1017/S0140525X01000061

Thomas, L. E. (2013). Spatial working memory is necessary for actions to guide thought.

Journal of Experimental Psychology: Learning, Memory, and Cognition. *39*, 1974-1981.

doi: 10.1037/a0033089

Thomas, L. E., & Lleras, A. (2007). Moving eyes and moving thought: On the spatial

compatibility between eye movements and cognition. *Psychonomic Bulletin & Review*,

14, 663-668. dx.doi.org/10.3758/BF03196818

Thomas, L. E., & Lleras, A. (2009). Covert shifts of attention function as an implicit aid to insight. *Cognition*, *111*, 168-174. dx.doi.org/10.1016/j.cognition.2009.01.005

Thomas, M. S., & McClelland, J. L. (2008). Connectionist models of cognition. *The Cambridge handbook of computational psychology*, 23-58. dx.doi.org/10.1017/CBO9780511816772.005

Uttal, William R. (2003). *The New Phrenology: The Limits of Localizing Cognitive Processes in the Brain.* Cambridge, Mass.: MIT Press.

Appendix A

The Revised Edinburgh Handedness Inventory (Dragovic, 2004; Oldfield, 1971) has both

high validity and reliability, with a test-retest reliability of 98.5% in 735 participants

tested 18 months apart (Ransil & Schachter, 1994; Dragovic, 2004). It is scored by

coding each of the eight responses in the following manner: -50 = always left, -25 =

usually left, 0 = no preference, 25 = usually right, 50 = always right. These values are

then added up and divided by 4, to give a value ranging from -100 (complete left

handedness) to +100 (complete right handedness). Only participants scoring 80 or higher,

denoting a strongly right-handed individual, were allowed to participate (Dragovic, 2004;
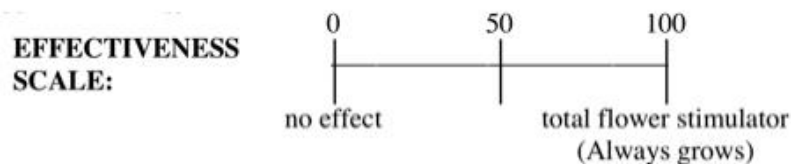
Oldfield, 1971).

Appendix B

Instructions for participant

You were cleaning out your garage and found four colored liquids. You vaguely
remember that some of these liquids might be plant fertilizers, plant herbicides, or they
might have nothing to do with plants. You have decided to investigate the effect that
these liquids have by pouring them onto a plant.

On each trial you will see a plant with a liquid next to it. If the liquid is in the air, this
indicates that it was used on the plant in that trial. If the liquid is on the ground, this
indicates that it was NOT used on the plant in that trial. Your task will be to make a
prediction (YES or NO) as to whether the plant will bloom. When you have made your
prediction, simply verbalize your response. After making your prediction, you will
receive feedback as to whether the plant bloomed or did not bloom.

At several points throughout the experiment, you will be asked to rate the relationship
between each of the liquids and plant blooming using the following scale

EFFECTIVENESS SCALE:

```
        0           50          100
        |           |           |
     no effect           total flower stimulator
                              (Always grows)
```

A rating of 0 corresponds to the liquid having no effect on plant blooming.

A rating of +100 corresponds to the liquid always causing plant blooming.

Before the experiment begins, I will have to calibrate the eye tracker to make sure it can follow your eye movements. During calibration, simply follow the red dot across the screen and make sure not to move your head.

Do you have any questions? When the experiment is done you will be asked to complete a short questionnaire and then will be debriefed.

Thank you for your participation.

The contingency and causal direction variables were treated as within-groups variables and marble movement and group were treated as between-subjects variables. Although no effect of causal direction was found (F (1,72) = 2.412, p = 1.25, η_p^2 = .032), a significant interaction between contingency, causal direction, and order was found (F (3,72) = 3.312, p = 0.024, ηp^2 = .121) indicating order effects. Bonferroni corrected post-hoc tests yielded significant comparisons between direction of causal elements within groups, however, no significant differences between groups or between movement conditions was found. Descriptive statistics were further used in an attempt to interpret any systematic changes or differences evident in the data, however, none was found. In an attempt to further elucidate the order effects, analyses in the body of the paper were performed examining what causal conditions subjects did first. Table 7 below depicts the nonsignificant effects and interactions. Table 8 and 9 below depict the order interaction from the experiment.

Table C.1

Statistics of non-significant effects for the order analysis

Effect	F	p-value	η_p^2
Contingency	1.22	0.274	0.02
Contingency * Movement	0.43	0.653	0.01
Contingency * Group	2.07	0.111	0.08
Contingency * Movement * Group	0.36	0.899	0.03
Cause Direction	0.99	0.322	0.01
Cause Direction * Movement	1.23	0.299	0.03
Cause Direction * Group	0.11	0.953	0.01
Cause Direction * Movement * Group	1.43	0.216	0.11
Cause Direction * Contingency	2.41	0.125	0.03
Contingency * Cause Direction * Movement	0.87	0.424	0.02
Contingency * Cause Direction * Group * Movement	1.26	0.289	0.10

Table C.2

Means of causal ratings by movement condition (Left to Right, Right to Left, No Movement), order, causal direction (L->R, R->L), and contingency (p=0, p=0.25) for the first and second order. Standard deviations in parenthesis.

		Order 1		Order 2	
		R->L	L->R	R->L	L->R
Left to Right	p=0	68.33(13.92)	66.11(20.28)	68.57(8.52)	64.29(20.5)
	p=0.25	71.67(20.16)*	49.44(22.00)*	59.29(20.90)	67.14(16.29)
Right to Left	p=0	58.8(17.79)	64.9(23.81)	76.25 (10.31)**	40(29.44)**
	p=0.25	53.5(23.93)	62(17.51)	51.25(16.52)	58.75(10.31)
NoMovement	p = 0	62.5(13.59)	61.5(26.15)	70.4(27.72)	69.8(15.50)
	p=0.25	53.5(12.92)	46(19.55)	51(14.32)***	73.6(9.86)***

Note. A * denotes significant Bonferroni corrected post-hoc tests.

41

Table C.3

Means of causal ratings by movement condition (Left to Right, Right to Left, No Movement), order, causal direction (L->R, R->L), and contingency (p=0, p=0.25) for the third and fourth order. Standard deviations in parenthesis.

| | | Order 3 | | Order 4 | |
		R->L	L->R	R->L	L->R
Left to Right	p=0	70.33(9.9)****	45.83(21.31)****	51.43 (27.04)	56.43 (20.35)
	p=0.25	64.17(19.6)	64.17(18.55)	65.43 (11.75)	52.14 (24.98)
Right to Left	p=0	55(22.36)	64.17(29.57)	65 (11.18)	55.71 (30.88)
	p=0.25	52.5(29.11)	55.83(26.91)	62.14 (11.85)	61.43 (13.45)
NoMovement	p = 0	64.17(33.23)	66.67(36.56)	62.86 (19.12)	55 (28.43)
	p=0.25	64.17(34.12)	65.33(21.09)	62.86 (11.13)	65.71 (24.40)

Note. A * denotes significant Bonferroni corrected post-hoc tests

Appendix D

Table D.1

Statistics of non-significant effects for the behavioral analysis

Effect	F	p-value	η_p^2
Movement	0.03	0.968	0.01
Cause Direction	1.07	0.304	0.02
Contingency	1.42	0.238	0.02
Movement * Cause Direction	0.22	0.802	0.01
Movement * Contingency	0.47	0.626	0.01
Cause Direction * Contingency	0.43	0.514	0.01
Movement * Cause Direction * Contingency	0.11	0.893	0.01