Distribution Agreement

Samuel Ritter 4-18-2011

Causation and the Somatosensory System

by

Samuel Ritter

Phillip Wolff
Adviser

Department of Psychology

Phillip Wolff

Adviser

Lawrence Barsalou

Committee Member

Michelangelo Grigni

Committee Member

Stella Lourenco

Committee Member

Valerie Summet

Committee Member

4-18-2011

Causation and the Somatosensory System

By

Samuel Ritter

Phillip Wolff

Adviser

An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Department of Psychology

2011

Abstract

Causation and the Somatosensory System
By Samuel Ritter

The role of the somatosensory system in the representation of causal relationships was investigated in five behavioral experiments. In Experiment 1, it was found that participants were faster to respond to a haptic target when it was preceded by activation of the somatosensory system by a haptic prime than when it was preceded by an auditory or visual prime. In Experiments 2 - 4, the primes were replaced by videos depicting causal or similar non-causal events. Given the results from Experiment 1, it was predicted that if the somatosensory system is recruited during the representation of causal relationships then participants would be faster to respond to a haptic target after viewing causal videos than after viewing non-causal videos. The results were as predicted. This effect was not found in control conditions in which auditory or visual targets were used instead of haptic targets. In Experiment 5, the videos were replaced by sentences that described causal or similar non-causal events. It was predicted that if the somatosensory system is recruited to represent causal relationships during language comprehension then participants would be faster to respond to a haptic target after reading causal sentences than after reading non-causal sentences. Results of this experiment did not support the contention that reading causal sentences activates the somatosensory system. Implications for theories of causation are discussed.

Causation and the Somatosensory System

By

Samuel Ritter

Phillip Wolff

Adviser

A thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Department of Psychology

2011

Acknowledgements

I would like to thank my adviser Phillip Wolff and all of the people who helped to run participants in the experiments described in this thesis: Kevin Holmes, Nirvi Shah, Jodi Lee, Kelsey Jamerson, Byron Liu, David Molho, and Kelsey Hodge. I would also like to thank the members of my defense committee for their insight and support.

Table of Contents

Causation and the Somatosensory System

Sam Ritter

Emory University

Abstract

The role of the somatosensory system in the representation of causal relationships was investigated in five behavioral experiments. In Experiment 1, it was found that participants were faster to respond to a haptic target when it was preceded by activation of the somatosensory system by a haptic prime than when it was preceded by an auditory or visual prime. In Experiments 2 - 4, the primes were replaced by videos depicting causal or similar non-causal events. Given the results from Experiment 1, it was predicted that if the somatosensory system is recruited during the representation of causal relationships then participants would be faster to respond to a haptic target after viewing causal videos than after viewing non-causal videos. The results were as predicted. This effect was not found in control conditions in which auditory or visual targets were used instead of haptic targets. In Experiment 5, the videos were replaced by sentences that described causal or similar non-causal events. It was predicted that if the somatosensory system is recruited to represent causal relationships during language comprehension then participants would be faster to respond to a haptic target after reading causal sentences than after reading non-causal sentences. Results of this experiment did not support the contention that reading causal sentences activates the somatosensory system. Implications for theories of causation are discussed.

Causation and the Somatosensory System

Causal knowledge plays a critical role in the processes by which humans understand their physical and social worlds. By enabling us to connect units of experience, it helps us to plan and execute adaptive actions. Due to its importance in human cognition and behavior, cognitive scientists have endeavored to explain how humans acquire knowledge of causal relations. The nature of this explanation is likely dependent on the types of causal relations under scrutiny. For example, some causal relations are realized over large expanses of time and space such as the effect of inflation on the economy. Other causal relations involve entities and processes that cannot be visually observed, such as the effect of an influx of sodium ions on the electrochemical gradient of a neuron. In between these extremes lie observable causal scenarios like the smashing of a window by a baseball or the transference of energy between two pool balls. Such observable scenarios are especially worthy of study because they may serve as a template for the human understanding of imperceptibly large or small varieties of causation (Rips, 2011). For this reason I have begun my investigation of causality by studying the representation of causal relations in observable scenarios.

By far the most extensively studied example of observable causation is the so called launching event (Michotte, 1963; Scholl & Tremoulet, 2000). In a basic launching event, one object (A) moves toward another object (B) in a straight line and at a constant rate. When A reaches B, A abruptly stops and B suddenly begins moving in the same direction that A was moving. Michotte (1963) studied the perception of causation by showing participants launching events instantiated by a mechanical apparatus that moved the two objects without any interaction between them. Although people were aware of the nature of the stimuli, when asked to describe the event they overwhelmingly described it as a causal interaction between A and B. This phenomenon has been referred to as the “impression of causality” (Michotte, 1963, p. 41) or as “phenomenal causality” (Scholl & Tremoulet 2000).

Michotte‟s finding opened up a debate about the mechanisms behind the impression of causality. Some researchers have argued that it is due to an encapsulated and innate visual module (Scholl & Tremoulet 2000, Saxe & Carey 2006). In this view, only visible properties such as shape, size, spatial relationships, and velocity are involved in the formation of the causal impression. Borrowing terminology used in physics, I will refer to these properties as kinematics. Other researchers have contended that invisible properties such as force and mass are also involved in the computation of causal relationships. Again borrowing from physics terminology, I will refer to both the visible and invisible properties of motion events as dynamics. Proponents of this second view argue that people infer dynamic properties from kinematics and use them to represent causal relations (White, 2006, 2009; Wolff, 2007, 2008, 2010).

Michotte argued for the kinematics-only explanation based on a physically impossible variation of the launching event that elicited the causal impression (Michotte, 1963). In one of his experiments, both A and B moved in the same direction at the beginning of the event and A moved faster than B. When A made contact with B, B decelerated. Participants reported that A caused B to slow down. Michotte argued that if people were referring to models of dynamics then this situation would have been recognized as impossible and an impression of causality would not have been produced. In a second variation from the basic launching event, participants did not report an impression of causality, even though Michotte claimed the event was possible and causal. In this event, A contacted a stationary B, and B began moving at a non-straight angle to the direction of A‟s motion. The reported impression of causality grew weaker as the angle between A‟s motion and B‟s motion approached 90 degrees. Michotte held that in real world launching events, objects such as marbles and billiard balls can be launched in directions at non-straight angles to the direction of the launching object. As such, if people used a model of dynamics they should have recognized his stimuli as a possible causal event and an impression of causality should have been produced. For a review of more recent arguments for this view, see Scholl and Tremoulet (2000).

On the other side of the debate, evidence in support of the role of dynamics in the perception of causation has been found in research testing Wolff's (2007) dynamics model of causation. In Wolff's theory, the patients and agents of causal scenarios are associated with patterns of forces with direction and magnitude. Based on the direction and relative magnitude of the forces (as computed from kinematic information), people are able to assign causal labels such as *cause*, *allow*, or *enable* to interactions between entities. This theory was supported by experiments in which a physics simulator was used to systematically manipulate the magnitude of forces acting in causal interactions and participants made judgments about the nature of the causal relationship (Wolff, 2007, 2010). Although Wolff‟s theory and its supporting evidence lend weight to the hypothesis that people‟s representations of causal relationships incorporate dynamic properties, it does not actually address the question of whether people have access to and can represent dynamic properties.

White (2007, 2009) addressed this question with his proposal that people can represent dynamic properties via the medium of memories of actions on objects. White asserted that the haptic and proprioceptive systems (hereafter referred to jointly as the somatosensory system) form representations of dynamic properties (e.g. force, mass) during interactions with objects. For example, when a person wields a baseball bat, their somatosensory system constructs a model that includes information such as the perceived mass of the bat and the amount of force required to move the bat at a certain speed. This model is constructed based on the amount of exertion required to move the bat and the amount of perceived resistance supplied by the bat (White, 2009). White posited further that when people view a launching event, they match its kinematic properties with those of a stored somatosensory representation of an action on an object. This representation forms a model of the dynamic properties of the event. In these models, object A is understood as the agent who exerts force to manipulate object B. White noted that when humans act on an object they perceive the force they are exerting as *overcoming* the resistance exerted by the object. This leads people to the erroneous belief that that they impart more force on the object than the object imparts on them. White reasoned that people's models of dynamics should also have this property; that is, if people use somatosensory models of actions on objects to represent the dynamic properties in launching events, then they should construe the force passing from A to B in a launching event as stronger than the force passing from B to A. This prediction was supported by the results of a study in which participants were shown launching events then asked to rate the amount of force exerted by each object (White, 2007, 2009). Participants reported that object A exerted more force on B than B exerted on A. White's findings are consonant with the hypothesis that somatosensory models of dynamics are used to represent the causal relationships inherent to launching events. However, his experiments relied on explicit judgments which could have been biased by higher level conscious processing. White‟s hypothesis would derive much greater support from direct evidence from an implicit measure that the somatosensory system is activated during the perception of launching events.

The present research uses an implicit measure of somatosensory activation to test whether the somatosensory system is activated by the presentation of causal stimuli. A testable prediction can be generated for this purpose: if this proposal is true, then presenting causal stimuli should have some of the same epiphenomenal effects as activating the somatosensory system in other ways, such as by directly stimulating peripheral haptic receptors. We suspected that one such epiphenomenal effect might be that sensitivity to haptic stimulation is enhanced or diminished by prior activation of the somatosensory system. In other words, we suspected that people would be faster or slower to respond to haptic stimulation if they recently perceived haptic stimulation. If this was true, then we could ascertain whether viewing launching events activates the somatosensory system by testing whether people are more or less sensitive to haptic stimulation after viewing launching events. To conduct this research, we used a tool called a haptic controller, a programmable device that is capable of generating precise motion (see Figure 1).

************ Insert Figure 1 about here **************

Figure 1: The Novint Falcon haptic controller

Our first goal was to establish whether somatosensory stimulation affects later haptic sensitivity, and if so, what the nature of this effect is. This was the purpose of Experiment 1, in which participants felt a motion generated by the haptic controller then performed a reaction time task in which they responded to the motion of another haptic controller. Their performance was compared to trials in which they were presented with an auditory or visual stimulus then performed the same reaction time task. This design allowed us to determine how activation of the somatosensory system affects people's sensitivity to later haptic stimulation, as measured by reaction time. The results of Experiment 1 created a foundation for Experiments 2 through 5 which test whether the presentation of various types of causal stimuli affects people"s sensitivity to haptic stimulation in the same way as activation of the somatosensory system by haptic stimulation. We predicted that if the formation of the causal impression requires activation of the somatosensory system, then viewing causal events will have the same effect on sensitivity to touch as activation of the somatosensory system by direct stimulation of touch receptors.

Experiment 1

In the Experiment 1, we investigated whether haptic stimulation enhances or diminishes sensitivity to haptic stimulation several hundred milliseconds later. Participants felt a haptic controller move, saw an „X" flash on a monitor, or heard a bell sound through headphones, then pressed a button as quickly as they could after feeling another haptic controller move. This movement of the second haptic controller and other stimuli that prompt participants to respond will be referred to in this paper as targets.

Spence, Driver, and Nicholls (2001) performed a similar experiment in which participants performed reaction time tasks to haptic, auditory, or visual targets. They found that people were faster to respond to a haptic target when their most recent trial included a haptic target than if it instead included an auditory or visual target. This finding supports the notion that haptic stimulation enhances sensitivity to later haptic stimulation. However, it is possible that the results from Spence et al. were not due to priming in the case of multiple successive haptic trials, but instead to a cost of switching attention from the other modalities in the case of unmatched successive trials. Our task is designed to rule out that interpretation – participants were able to keep their attention fixed on the haptic modality during all trials, since that is the only modality on which targets were presented. If the decreased reaction time shown by Spence et al. is due to an effect of priming by haptic stimulation, then participants in our task will be faster to respond to the haptic target after being primed with a haptic stimulus than after being primed with an auditory or visual stimulus.

Method

Participants. Twenty-five Emory University undergraduates received course credit or payment for participating in the experiment. All participants were right handed.

Materials. The haptic prime and target were generated by two separate Novint NF1 S01 (Falcon) haptic controllers, which are capable of generating and recording motion in a 4"x4"x4" workspace with precision of at least 400 dots per inch. The controllers were programmed using C++, the HAPI haptics development library, and the Novint HDAL haptics development library. The controller handle was positioned approximately 7 centimeters higher than the table. The visual target was a 30x24 pixel black „X" on a white background and was presented on a Dell 1901FP 19" monitor. The auditory prime was presented through Sony MDR W08 in-ear earphones and was approximately 15 dB loud in a mid to high frequency range. All elements of this experiment were implemented using C++ and the Simple DirectMedia Layer multimedia library.

Design and Procedure. Participants performed 24 practice trials and 60 experimental trials and were primed with an equal number of haptic, auditory, and visual stimuli in each set. They sat with their forearms resting comfortably on the table and with their right hands clasping the handle of the controller such that their index fingers touched the button on the top of the handle. A second haptic controller was placed so that its handle made contact with the back of participants" right hands. In each trial, participants felt a motion from the second haptic controller, saw an „X" flash on the monitor, or heard a sound through headphones. Each prime lasted 20 milliseconds. After an interval of 850, 950, 1050, or 1150 milliseconds the first haptic controller moved, and participants pressed the button on top of the first controller as quickly as they could.

Results and Discussion. The results showed that activation of the somatosensory system by haptic stimulation increases sensitivity to later haptic stimulation. As shown in Figure 2, participants were faster to respond to a haptic target after being primed with a haptic stimulus than after being primed with an auditory or visual stimulus. Participants were also faster to respond to a haptic target after being primed by an auditory stimulus than after being primed by a visual stimulus.

************ Insert Figure 2 about here ********

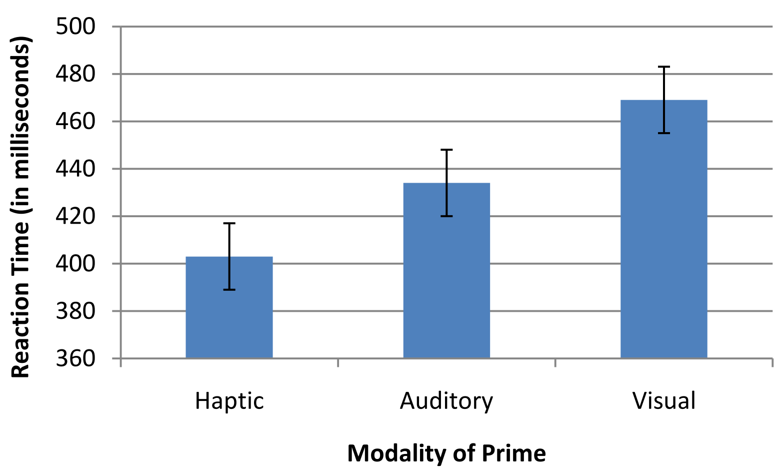

Figure 2: Results from Experiment 1 showing time to respond to a haptic target when it was preceded by another haptic signal, an auditory signal, or visual signal, with associated standard errors of the mean.

These findings were supported by *t*-tests on reaction times. Participants were faster to respond to a haptic target when it was preceded by a haptic prime (M = 403 ms) than when it was preceded by an auditory (M = 434 ms) prime, $t(23) = 2.22$, $p < .01$. Participants were also faster to respond to a haptic target when it was preceded by a haptic prime than when it was preceded by a visual prime (M = 469 ms), $t(23) = 4.24$, $p < .01$. Participants were faster to respond to a haptic target when it was preceded by an auditory prime than when it was preceded by a visual prime, $t(23) = 2.84$, $p < .01$.

The results of Experiment 1 show that activation of the somatosensory system enhances sensitivity to haptic stimulation. This finding has the important implication that activation of the somatosensory system can be measured by time to react to a haptic target. Given this finding, we are now in a position to examine whether the somatosensory system is activated by the perception of causal events. The following three experiments test whether viewing causal events activates the somatosensory system by measuring time to react to a haptic target after viewing causal and non-causal videos.

Experiment 2

In Experiment 2, we investigated whether viewing schematic animations of launching events alters people's sensitivity to haptic stimulation. Participants were shown causal videos of two red circles enacting a launching event against a black background or non-causal videos in which a red circle simply moved across the screen. Prior research has shown that the launching event sometimes needs to be shown several times before the impression of causality emerges (Michotte, 1963; Thinès, Costall, & Butterworth, 1991). As a consequence, causal and non-causal videos were shown four consecutive times in each trial. After viewing the videos, participants performed a reaction time task. Two precautions were taken to minimize participants‟ ability to predict the target, ensuring that any effects were due to the causal nature of the videos and not to the temporal characteristics of the task. First, the speed of the first three repetitions of the videos was randomly varied to prevent participants from establishing a rhythm based on recurring events in the videos. Second, the time between the end of the last video and the target was randomly varied so that the target would be more difficult to predict.

Experiment 1 showed that priming by a haptic stimulus resulted in increased haptic sensitivity. In the current experiment, the haptic prime was replaced by a video depicting a causal transference of forces, specifically, a launching event. The current experiment tests the hypothesis that when people see causal interactions they represent the underlying dynamic properties in the somatosensory system. If this representation of dynamic properties in the somatosensory system involves some of the same processes responsible for the perception of a haptic stimulus, then participants will be faster to respond to the somatosensory target after viewing causal videos than after viewing non-causal videos. In other words, inferring and representing a causal relationship will affect the somatosensory system in the same way as perceiving haptic stimulation. Based on this reasoning, it was predicted that participants would be faster to respond to the somatosensory stimulus after viewing causal videos than after viewing non-causal videos.

While this prediction is consistent with the hypothesis that the somatosensory system is involved in the perception of causation, it is also consistent with other less interesting possibilities. For example, seeing a causal interaction may be more interesting than seeing a non-causal event so that causal interactions will elicit greater arousal resulting in decreases in reaction time. Alternatively, it might be that causal videos provide more information about when the controller will move than non-causal videos do, enabling participants to better predict the motion. To guard against these alternative explanations, we included two other conditions. In the auditory condition, participants watched the animations then pressed a button as soon as they heard a sound through the headphones. In the visual condition, participants watched the animations then pressed a button as soon as they saw a dot appear on the screen. If people are faster to respond to a haptic target after watching a causal interaction than after watching a non-causal interaction because of differences in arousal or temporal signals, then they should also be faster to respond to the auditory and visual targets after watching a causal interaction than after watching a non-causal interaction. However, if this difference in time to respond to a haptic target is due to priming of the somatosensory system, then participants should not be faster to respond to the auditory and visual targets after watching a causal interaction than after watching a non-causal interaction.

The auditory and visual conditions were also included to test the possibility that viewing causal videos primes the motor system rather than the somatosensory system. The finding that people are faster to respond to a haptic target after seeing a causal event could be interpreted to mean that the causal event primed the motor system, allowing people to generate the motor command to press the button more quickly. If this were true, then people would be faster to respond to any target after viewing causal events than after viewing non-causal events, no matter what the modality. However, if viewing causal events primes the somatosensory system and thereby allows people to more quickly detect haptic stimulation, then people should only be faster to respond to haptic targets after viewing causal videos than after viewing non-causal videos. Therefore, if people are only faster to respond to haptic targets after viewing causal videos and are not faster to respond to auditory or visual targets, then the possibility that the motor system is being recruited instead of the somatosensory system will be ruled out.

Method

Participants. Thirty-six Emory University undergraduates received course credit or payment for participating in the experiment. All participants were right handed.

Materials. The videos were presented in an 800x600 pixel window on a Dell 1901FP 19” monitor. The monitor resolution was set at 1280x1024 pixels. The circles had a diameter of 45 pixels and the videos were created using a physics simulator and image renderer included with Autodesk's 3D Studio Max. The auditory stimulus was presented through Sony MDR W08 in-ear earphones and the sound used for the auditory target was approximately 15 dB loud in a mid to high frequency range. The visual target was a white dot on a black background that was 15 pixels in diameter. The haptic controller was a Novint NF1 S01 (Falcon), which is capable of generating and recording motion in a 4"x4"x4" workspace with precision of at least 400 dots per inch. The controller was programmed using C++ and the HAPI haptics development library. The controller handle was positioned approximately 11.5 higher than the table. The presentation of the videos and all other elements of this experiment were implemented using C++ and the Simple DirectMedia Layer multimedia library.

Design and Procedure. Participants were randomly assigned to either the haptic, auditory, or visual conditions. In all conditions there were 20 practice trials and 40 experimental trials. Causal videos were displayed in half of the trials in each set, and non-causal videos were displayed in the other half. Participants sat with their forearms resting comfortably on the table and with their right hands clasping the handle of the controller such that their index fingers touched the button on the top of the handle. In each trial, participants were shown four repetitions of a causal or non-causal video. For the first three repetitions, the speed of the video was randomized so that the video was either 540, 1440, 2340, or 3240 milliseconds long. The fourth video was always 1800 milliseconds long. At the end of the fourth video the animation paused, and the target was presented 100, 200, 300, 400, or 500 ms after the end of the video. The haptic target was a slight motion to the participants" right made by the haptic controller. The auditory target was a computer generated bell sound played through headphones. The visual target was a small white dot that appeared above the right circle in the animation. Each target lasted 20 milliseconds. Figure 3 shows the trial structure.

********** Insert Figure 3 about here **********

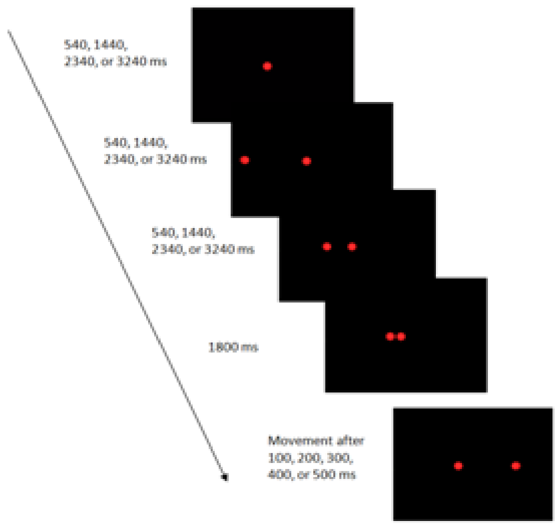

Figure 3: The trial structure of Experiment 2

Results and Discussion

The results supported the contention that viewing highly schematic depictions of launching events alters people's sensitivity to haptic stimulation. As shown in Figure 4, participants were faster to respond to a haptic target after viewing causal videos than after viewing non-causal videos. There was no significant difference in the speed at which participants responded to auditory or visual targets after watching videos of causal and non-causal events. Hence, the effect of video type (causal, non-causal) was specific to haptic stimulation.

*************** Insert Figure 4 about here **************

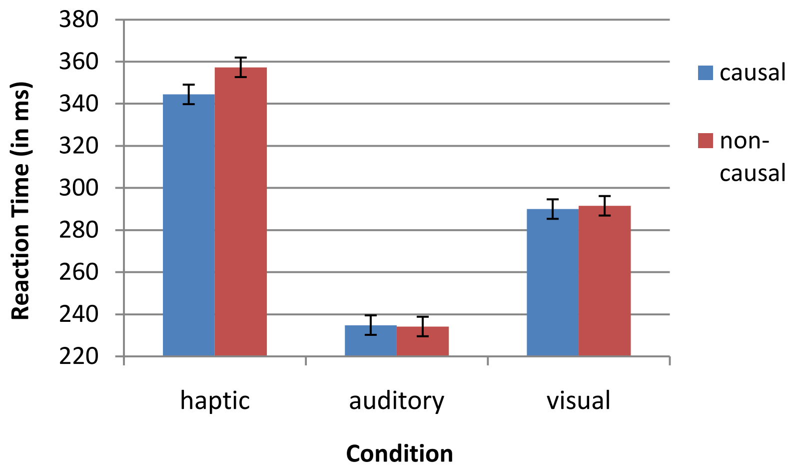

Figure 4: Results from Experiment 2 showing time to respond to a haptic, visual, or auditory target when it was preceded by four presentations of a schematically rendered causal or a non-causal video**.** Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

.

These findings were supported by *t*-tests on reaction times. Participants were faster to respond to a haptic target after viewing causal videos (M = 344 ms) than after viewing non-causal videos (M = 357 ms), $t(9) = 3.00$, $p < .01$. There was no evidence that participants were faster to respond to an auditory target after viewing causal videos (M = 235 ms) than after viewing non-causal videos (M = 234 ms), $t(11) = 0.30$, p > .1. There was also no evidence that participants were faster to respond to a visual target after viewing causal videos (M = 289 ms) than after viewing non-causal videos (M = 292 ms), $t(10) = 0.84$, p > .1.

The results of Experiment 2 provide the first direct behavioral evidence that the somatosensory system is involved in the perception of phenomenal causality, at least for schematically rendered events. Holmes and Wolff (2010) showed that people are more likely to simulate forces when schematically rendered scenes than when viewing realistically rendered scenes. Thus, it could be that the effect found in this experiment is limited to the schematic stimuli used and may not be present during real-world processing. I investigated this possibility in the next experiment by increasing the richness of the causal and non-causal videos.

Experiment 3

In Experiment 3, I investigated whether viewing richly rendered depictions of launching events increases people‟s sensitivity to haptic stimulation. Participants were shown causal videos of two marbles on a table enacting a launching event against a realistic background or similar non-causal videos in which a marble simply rolled across the table (see Figure 5). As in Experiment 2, videos were shown four times per trial to ensure the emergence of the impression of causality, the speed of the videos was randomized to prevent participants from establishing a rhythm, and the time between the end of the last video and the target was randomized to prevent participants from predicting the occurrence of the target.

**************** Insert Figure 5 about here ***************

Figure 5: An example frame from the causal video used in Experiment 3

In Experiment 2 it was found that the presentation of schematically rendered causal videos shortens reaction time to a haptic target. The purpose of the present experiment is to test whether this effect only holds for schematic stimuli like Michotte‟s (1963), or if it generalizes to more realistic, real-world situations. Based on the results of the previous experiments, I predicted that participants would be faster to respond to the haptic target after viewing causal videos than after viewing non-causal videos.

Method

Participants. Thirty-seven Emory University undergraduates received course credit or payment for participating in the experiment. All participants were right handed.

Materials. All materials were exactly the same as in Experiment 1, except that the animations were re-rendered in 3D Studio Max to include fine textures and a rich background scene, specifically, a blurry picture of a kitchen.

Design and Procedure. The design and procedure were exactly the same as in Experiment 2.

Results and Discussion

The results provide further support for the contention that the perception of phenomenal causality invokes the somatosensory system when the stimulus is richly detailed. As shown in Figure 6, participants were faster to respond to a haptic target after viewing causal videos than after viewing non-causal videos. There was no significant difference in the speed at which participants responded to auditory and visual targets after watching videos of causal and non-causal events. Hence, the effect of video type (causal, non-causal) was specific to the detection of haptic stimulation.

*************** Insert Figure 6 about here **************

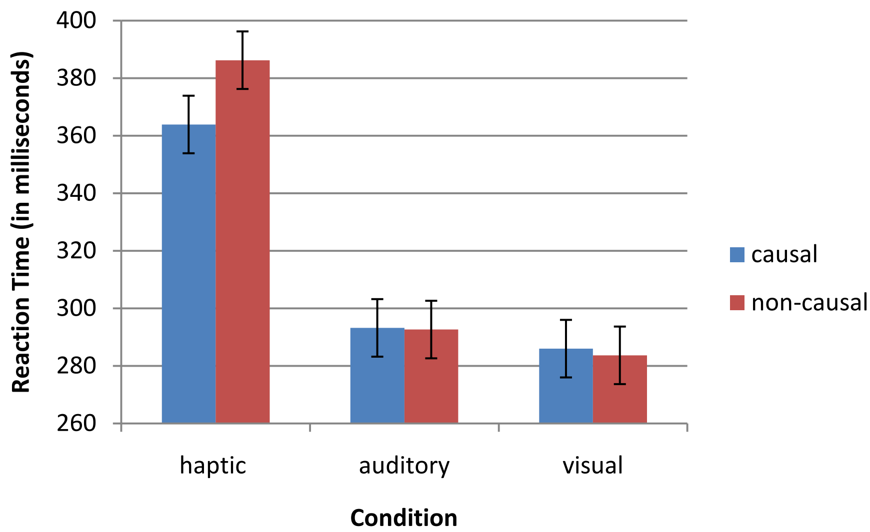

Figure 6: Results from Experiment 3 showing time to respond to haptic, visual, and auditory targets when they were preceded by four presentations of a richly rendered causal or non-causal video. Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

These findings were supported by *t*-tests on reaction times. Participants were faster to respond to a haptic target after viewing causal videos (M = 364 ms) than after viewing non-causal videos (M = 386 ms), $t(11) = 2.81$, $p < .05$. There was no evidence that participants were faster to respond to a visual target after viewing causal videos (M = 286 ms) than after viewing non-causal videos (M = 284 ms), $t(10) = 1.21$, $p > .1$. There was also no evidence that participants were faster to respond to an auditory target after viewing causal videos (M = 293 ms) than after viewing non-causal videos (M = 293 ms), $t(10) = 0.76$, p > .1.

The results of Experiment 3 provide evidence that the somatosensory system is involved in the perception of phenomenal causality in rich, real-world events. Admittedly, it is possible that the priming seen in the last two experiments is specific to the launching event. There are many other physical events that give rise to the impression of causation. As such, in order to confidently make the claim that the somatosensory system is recruited during the perception of phenomenal causality, it is important to be sure that the effect found in Experiments 2 and 3 holds for a variety of causal events. In the next experiment, we tested whether viewing videos depicting a marble shattering a glass cup also increase sensitivity to haptic stimulation.

Experiment 4

In Experiment 4, we investigated whether viewing non-launching causal events produces enhanced sensitivity to haptic stimulation. Participants were shown videos in which a marble rolled across a table and shattered a glass cup, an event that I will hereafter call a shattering event (see Figure 7). In the non-causal control condition, the video showed a marble roll across a table. As in Experiments 2 and 3, videos were shown four times per trial to ensure the emergence of the impression of causality, the speed of the videos was randomized to prevent participants from establishing a temporal rhythm, and the time between the end of the last video and the target was randomized to prevent participants from predicting the target.

**************** Insert Figure 7 about here ***************

Figure 7: A sample frame from the causal video used in Experiment 4

Experiments 2 and 3 showed that the presentation of launching events shortens reaction time to a haptic target. The purpose of the present experiment was to test whether this effect holds for other types of causal interactions. In the launching event, people perceive that the primary effect of the causal interaction is a change in the velocity of object B (Michotte, 1963). Based solely on the last two experiments, it could be argued that the activation of the somatosensory system after watching our videos is specific to causal interactions in which the primary effect is the change in velocity of an object. In the current experiment, causal videos were shown in which the primary effect of the causal interaction was not a change in velocity, but instead a deformation of an object. If the somatosensory system is activated by the perception of causation generally and not just by the perception of launching events, then participants will be faster to respond to the haptic target after viewing shattering events than after viewing similar non-causal events.

Method

Participants. Thirty one Emory University undergraduates received course credit or payment for participating in the experiment. All participants were right handed.

Materials. All materials were exactly the same as in Experiments 2 and 3, with the exception of the content of the videos, which was also created using Autodesk‟s 3D Studio Max.

Design and Procedure. The design and procedure were exactly the same as in Experiments 2 and 3.

Results and Discussion

The results supported the contention that viewing shattering events increases people's sensitivity to physical force. As shown in Figure 8, participants were faster to respond to a haptic target after viewing causal videos than after viewing non-causal videos. There was no significant difference in the speed at which participants responded to auditory and visual targets after watching videos of causal and non-causal events. Hence, the effect of video type (causal, non-causal) was specific to the detection of haptic stimulation.

These findings were supported by *t*-tests on reaction times. Participants were faster respond to a haptic target after viewing causal videos (M = 346 ms) than after viewing non-causal videos (M = 353 ms), $t(10) = 2.62$, $p < .05$. There was no evidence that participants were faster to respond to a visual target after viewing causal videos (M = 259 ms) than after viewing non-causal videos (M = 255 ms), $t(8) = 1.14$, p > .1. There was also no evidence that participants were faster to respond to an auditory target after viewing causal videos (M = 241 ms) than after viewing non-causal videos (M = 242 ms), $t(7) = 0.65$, $p > .1$.

**************** Insert Figure 8 about here ***************

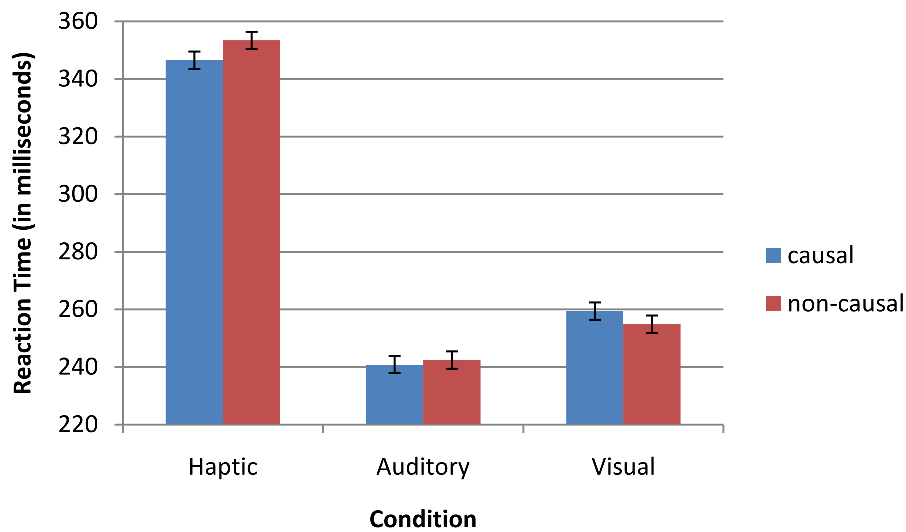

Figure 8: Results from Experiment 4 showing time to respond to a haptic, visual, or auditory target when it was preceded by four presentations of a video of a shattering event or a similar non-causal event. Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

The results of Experiment 4 provide evidence that the activation of the somatosensory system shown in Experiments 2 and 3 is not specific to the launching event, but generalizes to a variety of causal events. Together the first four experiments established strong evidence that the somatosensory system is active during the perception of causal events. The next and final experiment tested whether this activation is specific to phenomenal causality, or if it is also present during offline processing of causal language.

Experiment 5

In the current experiment, we investigated whether reading sentences that describe causal events increases haptic sensitivity. In the causal trials, participants read sentences that described either a transference of forces between objects or an object causing the deformation of another object (e.g. *An arrow pierced an apple*). In the non-causal trials, participants read non-causal sentences that were matched with the causal sentences for subject and object, differing only in the verb phrase (e.g. *An arrow flew past an apple*). After reading each sentence, participants performed a task in which they pressed a button as quickly as they could after feeling the motion of a haptic controller.

Experiments 2 through 4 showed that the somatosensory system is activated during the perception of phenomenal causality. With this established, we are now in a position to investigate whether the somatosensory system"s role in causal processing is specific to phenomenal causality, or if it underlies a wider variety of causal reasoning. In addition to inferring causal relationships from perceptual data, people also reason about causality offline during thought and linguistic processing. Causal knowledge is likely as fundamental to human organization of events in these contexts as is in the context of online processing of visual input. To investigate the possibility that the somatosensory system is recruited during language comprehension, we created an experimental design similar to the previous experiments in which the causal animations were replaced by brief sentences describing causal situations. Just like the events shown in the previous experiments, the events described in the sentences were observable causal scenarios involving concrete entities. If it is the case that the somatosensory system is recruited in the processing of linguistic descriptions of causal events, then people should be faster to respond to a haptic stimulus after reading a causal sentence than after reading a non-causal sentence.

Method

Participants. Fourteen Emory University undergraduates received course credit or payment for participating in the experiment. All participants were right handed.

Materials. The haptic target was generated by a Novint NF1 S01 (Falcon) haptic controller. The controller was programmed using C++ and the HAPI haptics development library. The controller handle was positioned approximately 11.5 centimeters higher than the table. The sentences were presented in black 18 point TTF_Font text on a Dell 1901FP 19" monitor. All sentences used are reproduced in the appendix. All elements of this experiment were implemented using C++ and the Simple DirectMedia Layer multimedia library.

Design and Procedure. Participants performed 10 practice trials and 50 experimental trials. They sat with their forearms resting comfortably on the table and with their right hands clasping the handle of the controller such that their index fingers touched the button on top. In each trial participants saw a sentence on the screen for 3200, 3300, 3400, or 3500 milliseconds, and then felt the haptic controller move. Participants then pressed the button on top of the controller as quickly as they could after feeling the motion.

Results and Discussion

The results did not support the contention that reading causal sentences increases people‟s sensitivity to physical force. As shown in Figure 9, participants were no faster to respond to a haptic target after reading causal sentences (*M* = 302 ms) than after reading non-causal sentences (*M* = 303 ms), $t(12) = 0.79$, $p > .1$.

**************** Insert Figure 9 about here ***************

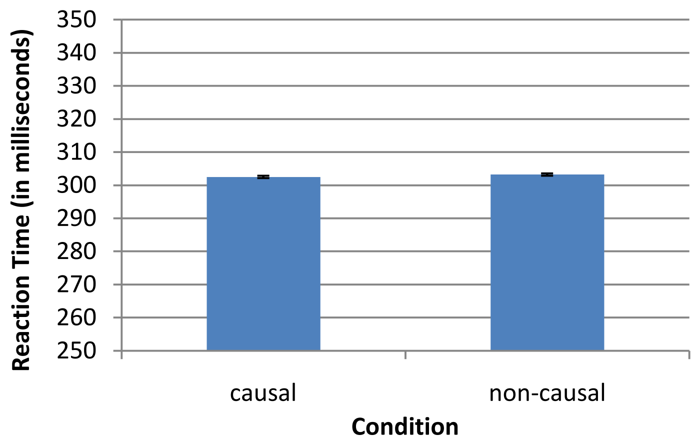

Figure 9: Results of Experiment 6 showing time to respond to a haptic target after reading causal and similar non-causal sentences. Error bars show 95% within-subjects confidence intervals (Loftus & Masson, 1994).

The results of Experiment 5 do not provide evidence that the somatosensory system is activated by the reading of causal sentences. This could be due to the fact that our paradigm did not precisely control the time at which participants processed the causal relationship described in the sentences. In the experiments that used videos, we were able to precisely control the time between the collision of the objects and haptic target. We found in pilot experiments that if the time between the collision and the haptic target was increased or decreased by even a few hundred milliseconds, the priming would no longer occur. In the present experiment, participants may have spent different amounts of time reading the sentence, such that the time between the processing of the causal relationship and the target was too long or short for priming to occur. Alternatively, it is possible that the somatosensory system is not involved in the offline processing of causation. It may be that somatosensory activation during the viewing of causal events is a purely perceptual phenomenon and that causal processing during language comprehension is accomplished by entirely different mechanisms. To investigate this further, it would be useful to perform an experiment in which the time course of participants‟ processing of the sentences is more precisely controlled. This could be accomplished by presenting recordings of someone reading the sentences instead of having participants read the sentences. This would allow us to ascertain whether or not the results of this experiment are due to inconsistencies between participants‟ reading time.

General Discussion

The results support the proposal that the somatosensory system is recruited during the perception of phenomenal causality, but did not support the notion that it is recruited during offline linguistic processing of causal events. Experiment 1 showed that activation of the somatosensory system by haptic stimulation increases haptic sensitivity. Experiments 2 through 4 showed that the same effect occurred when the initial haptic stimulation was replaced by a video depicting a causal event. In particular, Experiment 2 showed that viewing highly schematic depictions of launching events increases people‟s haptic sensitivity. Experiment 3 showed that the effect observed in Experiment 2 also holds for richly detailed depictions of launching events. Experiment 4 showed that viewing shattering events also increases people‟s sensitivity to haptic stimulation. In Experiment 5, evidence for the proposal that reading causal sentences increases haptic sensitivity was not found. This may have been because our paradigm did not control the time at which the causal relationship was processed precisely enough, or because the mechanisms that underlie the perception of phenomenal causality are different from those that underlie offline causal reasoning during language comprehension. The primary finding of this research is that the somatosensory system is activated during the viewing of causal events. This discovery has implications for the long-standing debate about the foundation of causal reasoning.

On one side of this debate are the physicalist theories (Wolff, 2008) which hold that people‟s representations of causation include reproductions of dynamic quantities in the world such as force and mass (Aronson, 1971; Fair, 1979; Dowe, 2000; Talmy, 1988; Wolff, 2007). These theories claim that humans understand the relationships between events as transferences of or interactions between conserved dynamic quantities. For example, Fair (1979) posited that causation is understood as quantities such as force, energy, or momentum flowing from the cause to the effect. At the heart of physicalist theories is the assumption that people have access to these invisible dynamic properties. Many, perhaps the majority of researchers interested in causal cognition have been unwilling to accept this assumption. Instead, they have adopted Hume‟s (1737) argument that these dynamic quantities cannot be accessed by sensory experience. Hume famously observed that people cannot visually perceive causal connections between antecedent and consequent events. He went on to argue that people must infer the connections between events based on repeated encounters with the same sequence of events. This argument has had a tremendous impact on thought and research about causation, to the extent that the currently dominant theories of causation are essentially well developed variations of it (Cheng &Novick, 1991; Pearl, 2000; Gopnik et al. 2004; Sloman, 2005). These theories characterize causal reasoning as a calculus of counterfactuals or statistical co-occurrences. For example, Cheng and Novick‟s (1991) probability contrast theory holds that when people see that the probability of an event A is greater given the presence of another event B, they will infer that B causes A. This class of theories fails to account for the fact that people often describe novel sequences of events as causal, and it does not explain why causes must precede effects. In addition, this class of theories is unable to motivate the main finding of Experiments 2 – 4. If people‟s causal reasoning is based solely on covariances between frequencies of events, then there is no reason that viewing causal events should prime the somatosensory system.

There is another view that can easily account for these phenomena which holds that the human conception of causation is rooted in agency and action. In this view, people understand the connection between cause and effect through their own experience of being causes. This view can be traced at least as far back as the 18th century when de Biran (1942) asserted that muscular exertion is the foundation of human understanding of causal relationships. He claimed that when people see one billiard ball bump another they understand the connection between the two balls through memories of physical exertion[1] (de Biran, 1942). In order for this view to plausibly explain how people understand visually perceived causal interactions, it must be shown that people can match visually perceived scenes with somatosensory representations of physical exertion.

Although there is no specific evidence for this, it has been shown that people are capable of computing dynamic properties such as relative mass based on kinematic properties (Runeson, Juslin, & Olsson, 2000). Also, there are many empirical examples of modalities working together to support online categorization, as this view suggests vision and somatosensation do to recognize causation. For example, audition and vision interact in the well-known McGurk effect, in which visual and auditory information are combined to determine phonemic categorization (McGurk& MacDonald, 1976). In another example, Blake et al. (2004) showed that visual cortex is activated during the performance of haptic object recognition and special discrimination tasks. Another fact that suggests that somatosensation could be involved in the representation of

[1] de Biran"s language of muscular exertion may indicate that he was asserting that the medium of representation of causal relationships is memories of actions in the motor system. This specific claim is not supported by our results. Instead, it seems that the medium of representation is memories of actions in the somatosensory system. See the section concerning Experiment 2 for a detailed explanation.

causation is its involvement in other so called higher cognitive processes such as the making of social judgments (Ackerman et al., 2010). Ackerman et al. showed that people‟s judgments of other people and situations could be influenced by various types of haptic experience. For example, people rated others as more dependable when the clipboard they were using to write down the ratings was heavy than when it was light.

In spite of this precedence for the idea that the somatosensory system could interact with the visual system to represent the dynamic quantities underlying causal events, this idea and the physicalist models that could find a basis in it have been ignored by the majority of scholars interested in causation. This could be in part because the neuroscience literature is divided on whether or not the somatosensory strip is activated by the viewing of causal events. Fugelsang et al. (2005) found that the postcentral gyrus was significantly more active during the viewing of causal launching events than during the viewing of similar non-causal events. However, Blakemore et al. (2001), Straube and Chatterjee (2010), and Fonlupt (2003) did not find activation of somatosensory areas during the viewing of launching events. The difference between these findings could be due to differences in the control non-causal videos used. The present research contributes to this research area by providing behavioral evidence that the somatosensory system is activated during the viewing of causal events.

In conclusion, the present research provides evidence for the contention that people have access to the invisible dynamic properties in the world through a process of matching kinematic quantities with representations of actions on objects. This is important because it helps to remove one of the greatest obstacles to the physicalist models of causation, namely the argument that people do not have access to invisible dynamic properties. Perhaps this finding will generate renewed interest in these physicalist models, allowing us to avoid the pitfalls of probabilistic theories. Perhaps more importantly, this research also develops a new behavioral method for studying the somatosensory underpinnings of causal reasoning. This method will allow us to test whether the somatosensory system is recruited during the processing of various kinds of causal relations. For example, it will allow us to test whether the somatosensory system is recruited during offline processing of concrete relations, or during the processing of abstract relations. In short, this method has the potential to increase not just our understanding of phenomenal causality, but of the foundation of causal knowledge in general.

References

Ackerman, J. M., Nocera, C. C., &Bargh, J. A. (2010). Incidental Haptic Sensations Influence Social Judgments and Decisions. *Science*, *328*, 1712-1715.

Black, R., Sobel, K. V., & Thomas, J. W. (2004). Neural Synergy Between Kinetic Vision and Touch.*Psychological Science*, *15*, 397-492.

Blakemore, S., Fonlupt, P., Pachot-Clouard, M., Darmon, C., Boyer, P., Meltzoff, A. N., et al. (2001). How the brain perceives causality: an event-related fMRI study. *NeuroReport*, *12* 3746-3746.

Cheng, P. W. (1997). From covariation to causation: A causal power theory. *Psychological Review*, *104*, 367-405.

de Biran, Maine. (1942). *Oeuvres choisies de Maine de Biran*. Paris: Aubier.

Dow, P. (2000). *Physical causation*. Cambridge: Cambridge University Press.

Fair, D. (1979). Causation and the flow of energy. *Erkenntnis*, *14*, 219-250.

Fonlupt, P. (2003). Perception and judgment of physical causality involve different brain structures. *Cognitive Brain Research*, *17*, 248-254.

Gopnik, A., Glymour, C., Sobel, D. M., Schulz, L. E., Kushnir, T., &Danks, D. (2004). A Theory of Causal Learning in Children: Causal Maps and Bayes Nets. *Psychological Review, 111*, 3-32.

Hume, David. (1737) *An Enquiry Concerning Human Understanding.* (2nd Ed.) Oxford: Oxford University Press.

Loftus, G. R., & Masson, M. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, 1(4), 476-490.

MacDonald, J., &McGurk, H. (1978). Visual influences on speech perception processes. *Perception & Psychophysics, 24*, 253-257.

Michotte, A. (1963). *The Perception of Causality*. London: Methuen.

Pearl, Judea (2000). Causality: Models, Reasoning, and Inference, Cambridge University Press.

Piaget, J. (1929). *The Child's Conception of the World. London*: Routledge and Kegan Paul, Ltd.

Rips, L. (2011). Causation From Perception. *Perspectives on Psychological Science*, *6*, 77-97.

Roser, M. E., Fugelsang, J. A., Dunbar, K. N., Corballis, P. M., &Gazzaniga, M. S. (2005). Dissociating Processes Supporting Causal Perception and Causal Inference in the Brain. *Neuropsychology, 19*, 591-602.

Runeson, S., Juslin, P., & Olsson, H. (2000). Visual perception of dynamic properties: Target heuristics versus direct-perceptual competence. *Psychological Review*, *107*, 525–555.

Saxe, R., & Carey, S. (2006). The perception of causality in infancy. *Acta Psychologica*, *123*, 144–165.

Scholl, B. J., & Tremoulet, P. D. (2000). Perceptual causality and animacy. *Trends in Cognitive Sciences*, *4*, 299-309.

Sloman, S. (2005). *Causal models: How people think about the world and its alternatives*. Oxford: Oxford University Press.

Spence, C., Nicholls, M. E. R., Driver, J (2001). The cost of expecting events in the wrong sensory modality. *Perception and Psychophysics*, *63*, 330-336.

Straube, B., Chatterjee, A. (2010). Space and time in perceptual causality. *Frontiers in Human Neuroscience*, *4*, 1-10.

Talmy, L. (1988). *Force dynamics in language and cognition*. Cognitive Science, 12,49-100.

Thinès, G., Costall, A., & Butterworth, G.E. (1991). Michotte's experimental phenomenology of perception. Hillsdale, NJ: Erlbaum.

White, P. A. (2006). The causal asymmetry. *Psychological Review*, *113*,132–147.

White, P. A. (2007). Impressions of force in visual perception of collision events: A test of the causal asymmetry hypothesis. *Psychonomic Bulletin & Review*, *14*, 647–652.

Wolff, P. (2007). Representing causation. *Journal of Experiment Psychology: General, 136*, 82-111.

Wolff, P. (2008). Dynamics and the perception of causal events. In T. Shipley & 3. Zacks (Eds.), *Understanding events: How humans see, represent, and act on events* (pp. 555 - 587). New York: Oxford University Press.

White, P. (2009). Perception of Forces Exerted by Objects in Collision Events. *Pyschological Review*, *116*, 580-601.

Wolff, P. (2010). For Want of a Nail: How absences Cause Events. *Journal of Experimental Psychology: General*, *139*, 191-221.

Wolff, P., Holmes, K. J. (2010). Linguistic Relativity. *WIRE's Cog Sci*, *104*, 1-13.

Appendix

Sentences used in Experiment 5

*A marble nudged another marble.
**A marble rolled past another marble.

*A baseball dented a car.
**A baseball sailed over a car.

*A domino knocked another domino down.
**A domino fell beside another domino.

*A car smashed into another car.
**A car passed another car.

*A bowling ball knocked a pin down.
**A bowling ball rolled by a pin.

*A softball broke a vase.
**A softball landed beside a vase.

*A rock cracked a windshield.
**A rock flew by a windshield.

*An arrow pierced an apple.
**An arrow flew past an apple.

*A cannonball destroyed a wall.
**A cannonball soared over a wall.

*A comet smashed into an asteroid.
**A comet soared past an asteroid.

---

*Causal

**Non-Causal