# Causation, Force, and the Sense of Touch

**Phillip Wolff (pwolff@emory.edu)**
Department of Psychology, 36 Eagle Row
Atlanta, GA 30322 USA
**Samuel Ritter (swritter@Princeton.edu)**
Department of Psychology, Green Hall
Princeton, NJ 08540 USA
**Kevin J. Holmes (kjholmes@berkeley.edu)**
Department of Linguistics, 1203 Dwinelle Hall
Berkeley, CA 94720 USA

**Abstract**

It is widely acknowledged that causation entails more than spatial-temporal contiguity or correlation, but efforts to specify that extra component of experience have been elusive. In this paper, we argue that the representation of causal relations is based on the feeling of force as understood through the sense of touch. Grounding causation in people's sense of touch allows us to address long-standing challenges that have been raised against force-based approaches to causation. In support of our proposal, we report a series of experiments showing that the perception of causation is associated with the notion of force, as indicated by changes in people's sensitivity to a physical force acting against their hand. We also show that when people associate correlations with force, they view those correlations as causal. Implications for understanding the origins of causal knowledge are discussed.

**Keywords:** Causation**;** Causal perception; Force Perception; Haptics; Causal Induction; Abstract Concepts

## Introduction

Several recent theories of causation have proposed that the mental representation of causation is based on the notion of *force* (Copley & Harley, 2014; Fales, 1990; Gärdenfors, 2000; Mumford & Anjum, 2011; Hubbard & Ruppel, 2014; White, 2012; Warglien, Gärdenfors, Westera, 2012; Wolff, 2007; Wolff, et al. 2010). These theories have provided explanations of how causal relations might be recognized from a single occurrence of an event (Ahn & Kalish, 2000; Bigelow, Ellis, & Pargetter, 1988; Wolff, 2007) as well as how different kinds of causal relationships might be related to one another (Talmy, 1988; see also Wolff, 2007; Wolff, et al., 2010). Despite these successes, there has been strong criticism of force-based accounts of causation (Cheng, 1997; Cheng & Novick, 1992; Schulz, Kushnir, & Gopnik, 2007; Woodward, 2007; Sloman, Barbey, & Hotalling, 2009). Arguably the most fundamental of these criticisms was initially made by Hume (1748/1975). He pointed out that the notion of force could not be linked to any internal or external sensory impression and that, therefore, forces could not be the basis for our mental representation of causation. He noted that after many repetitions of conjunctions of objects or events, people could develop an expectation that gives rise to a sense of power or force, but that this sense only emerged from statistical regularities, which were the only legitimate bases for inducing causation. Hume's arguments remain relevant today because they continue to be used in defense of probabilistic accounts of causation (e.g., Cheng, 1997; Cheng & Novick, 1991, 1992).

In this paper, we report a set of findings that addresses Hume's main criticism against force accounts of causation: specifically, that forces cannot be linked to internal or external sensory impressions. The criticism certainly holds in the case of the visual modality. However, once we consider the potential contributions of other senses, in particular touch, it becomes clear that people's sensory experience is not as deficient as Hume (and many modern theorists) have claimed. According to what we will call the *causal force hypothesis*, people's mental representation of causation is based on the feeling of force as understood through the sense of touch (see Fales, 1990; White, 2012).

### Perception of forces

Several lines of research have established that people are able to represent forces. These studies have shown that people are skilled at perceiving forces from the environment when those forces impinge directly on the skin. For example, Wheat, Salo, and Goodwin (2004) found a nearly linear relationship between participants' estimates of a force acting on their fingers and the actual magnitude of the force. Panarese and Edin (2011) found that people are quite good at discriminating the direction of forces applied to the index finger. Of particular relevance to the induction of causation, several neuroimaging studies have reported evidence for the encoding of forces even in the absence of physical contact. For example, Keysers et al. (2004) observed activity in the somatosensory cortex not only when people were touched directly on their legs, but also when they observed other people being touched on their legs. Even more impressively, activity in the somatosensory cortex was observed when participants observed one inanimate object touch another inanimate object. Keysers et al.'s (2004) findings have been replicated and extended in several other studies (see Blakemore, Bristow, et al., 2005; Ebisch, et al., 2008). Indeed, the representation of forces through the visual modality is revealed in common everyday tasks. Many of us, for example, have had the experience of reaching for a suitcase or box and over-lifting it because we thought it was full when, in fact, it was empty. Such events presumably occur because we estimate the weight of the suitcase, a type of force, before we lift it, and when we estimate wrongly, we generate greater-than-necessary forces. Clearly, the somatosensory system plays a role in the representation of forces in the physical world. It may also play a role in the representation of more abstract kinds of forces. For example, Lee and Schnall (2014) found that people with a low personal sense of power perceived loaded boxes as heavier than people with a high personal sense of power. These findings suggest that the somatosensory system may factor into the representation of abstract forces.

### Testing the link between causation and force

Figure 1. Haptic controller device.

According to the *causal force hypothesis*, people represent the notion of causation in terms of forces. The hypothesis implies that "seeing" forces might prime feeling forces; specifically, if people induce causation based on forces, seeing causal events may make them more sensitive to forces applied against their body. This prediction was tested using a haptic controller device (see Fig. 1). A haptic controller is essentially a small robotic arm that can be pushed around like a mouse, but unlike a mouse, it can also push back. In the following experiments, we programmed the haptic controller to generate a small force against people's hands after they watched causal and noncausal events, and measured how long it took for them to feel the force.

## Experiment 1

This experiment investigated whether seeing physical causation would prime feeling a force. Participants viewed either causal or non-causal events. In the causal event, one marble hit another and made it roll. In the non-causal event, one marble rolled across a surface without hitting another marble. If causation is based on force, then people should be faster to detect a force after watching the causal than the non-causal event. On its own, such a result would offer only modest support for the *causal force hypothesis* because the effect could be due to rather uninteresting reasons. In particular, the effect could arise if the causal events were better predictors of the onset of the force than the non-causal events. Alternatively, the causal events could be more interesting than the non-causal events, hence increasing people's arousal level and ultimately speeding their response time. We included two additional conditions to control for such possibilities. Specifically, two other groups of participants were asked to detect an auditory or visual signal rather than a force. These control conditions are important because if priming is observed in the force condition and it is due to uninteresting reasons such as predictability or arousal level, then similar effects should be observed in the visual and auditory conditions. In contrast, if there is an effect in the force condition but not in the auditory and visual control conditions, the overall pattern of results would suggest that the effect of seeing a causal event is specific to the somatosensory modality. In sum, the main prediction was that people would be faster to detect a force after seeing a causal than a noncausal event, but that no such difference would be found in the control conditions.

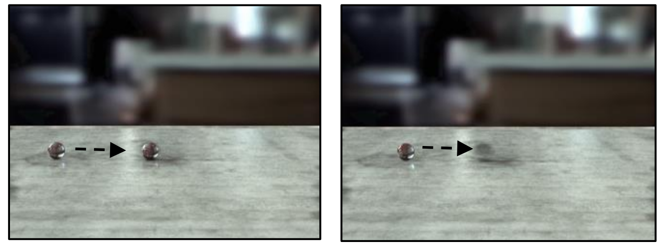

Figure 2. Frames from causal (left) and non-causal (right) animations used in Experiments 1.

### Method

**Participants** Ninety-three Emory University undergraduates participated for course credit or payment. Three participants were excluded for high error rates (> 25%) as determined by the criteria described below. Ultimately, the force, auditory, and visual conditions included 30 participants each.

**Equipment and Materials** The animations used in this experiment were rendered in the 3D animation package Autodesk 3D Studio Max (see Figure 2). The movements of the marbles were calculated using the physics simulator MasFX so as to resemble actual collisions (sample animations can be found at http://psychology.emory.edu/cognition/wolff/animations.html). The causal and non-causal animations were exactly the same in duration and in the path traveled by the marbles. The haptic controller device was made by Novint Technologies. The controller had a small button on its hand grip that allowed people to indicate when they felt a force. The controller was programmed using widely available C++ libraries, specifically using the H3D API.

**Procedure** In all three conditions, participants held the haptic controller while they watched each animation played 4 times. The first three times, the animations played at different speeds, randomly chosen, such that they lasted 540, 1440, 2340, or 3240 ms. The animation was played several times in order to "build up" the sense of force. The fourth time the animation played, it lasted an intermediate amount of time, 1800 ms. At the end of the animation, the last frame was paused, and the haptic controller moved 100, 200, 300, 400, or 500 ms after the onset of the last frame of the animation. The exact moment when the controller moved was varied to discourage pressing the button on the basis of prediction rather than actual movement. Participants in the force condition were instructed to press the button on the controller as soon as they felt it move, whereas participants in the auditory and visual conditions were instructed to press the button as soon as they heard or saw the auditory or visual signal. Onset of the force, sound, or visual signal was varied so that participants could not predict exactly when to press the button. The force generated by the controller was very small, specifically an impulse of 1.5 Newtons for 20 ms, which, phenomenologically, produced a very faint impression on the hand, but clearly above the sensory threshold for touch. It is likely that the impulse generated by the haptic controller lasted longer than 20 ms due to the effects of inertia on the haptic controller's arms. The auditory signal was an electronic "ding" that played for 20 ms. Because the signal was not followed by an auditory mask, the impression created by the sound lasted longer than 20 ms. The visual signal was a small black dot, 5 mm in diameter. It appeared 5 mm immediately above the marble that came to a stop at the end of the animation. The dot remained on the screen for 20 ms. As with the auditory signal, no mask followed the dot, so the impact of the visual signal lasted longer than 20 ms. There were 20 practice trials, half causal and half non-causal, and 40 experimental trials, half causal and half non-causal.

### Results and discussion

In this and the following experiments, reaction times less than 100 ms or greater than 2.5 standard deviations from an individual participant's mean were excluded. If the total number of excluded RTs exceeded 25% of the trials, the participant's data was not included in the analyses. On the basis of this criterion, the data from 3 participants were excluded from further analysis.

The results support the hypothesis that seeing a causal event affects people's sensitivity to a physical force. A mixed factors ANOVA indicated a significant interaction between event type (causal, non-causal) and signal type (force, sound, visual), thus showing that the time to detect a force after watching a causal versus a non-causal animation differed across the three conditions, $F(2,87) = 4.51$, $p = .014$, $\eta^2 = .094$. Most importantly, as shown in Figure 3 and supported by planned comparisons, people were faster to report feeling a force after watching a causal ($M$ = 334 ms; $SE$ = 20) than non-causal animation ($M$ = 349 ms; $SE$ = 23), $t(29) = -2.964$, $p = .006$, $d = .54$. Further planned comparisons provided no evidence that seeing causal versus noncausal animations had an impact on the time to detect an auditory, $t(29) = -0.68$, $p = .946$, or visual stimulus, $t(29) = -.592$, $p = .558$, suggesting that the effect found in the force condition cannot be explained as due to greater predictability of the signal or greater arousal in the causal than the non-causal condition. Rather, the overall pattern of results suggests that when people saw a collision event, they inferred a force, which affected their speed to respond to an actual physical force acting against their hand. Of less central interest, the ANOVA also indicated significant main effects of event type (causal, non-causal), $F(1,87) = 6.51$, $p = .012$, $\eta^2 = .07$, and signal type (force, sound, visual), $F(2,87) = 7.04$, $p = .001$, $\eta^2 = .139$.

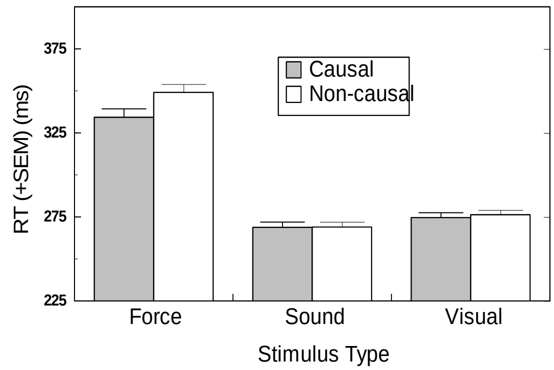


Figure 3. Results from Experiment 1.

## Experiments 2 - 4

The main goal in Experiments 2-4 was to determine whether the effects observed in Experiment 1 would extend beyond collision events. The methods and predictions in these experiments were exactly the same as in Experiment 1, but the kinds of causal events people saw were different. In Experiment 2, the causal animation showed a marble rolling into a glass and breaking it, whereas the noncausal animation simply showed a marble rolling across the table. The goal of this experiment was to examine whether forces are felt for changes of state as well as for changes in location. In Experiment 3, the causal animation involved flipping a switch and a light turning on, while the noncausal animation involved simply flipping a switch. Turning on a light is another type of change-of-state event but one in which the underlying mechanism is hidden. Of interest in this experiment was whether force effects might be observed even in the absence of direct physical contact. In Experiment 4, the animations depicted social causation. The causal animation showed a person directing another to change direction, while the noncausal animation simply showed a person running. Here the question concerned whether seeing social causation would prime a feeling of force.

### Method

**Participants** Emory University undergraduates participated for course credit or payment. Ninety-three participated in Experiment 2, 95 in Experiment 3, and 97 in Experiment 4.
**Materials** Two frames from the causal animations used in Experiments 2-4 are shown in Figure 4. As in Experiment 1, the animations were run at different speeds and lasted 540, 1440, 2340, or 3240 ms.

### Results and discussion

Three, five, and seven participants were excluded in Experiments 2 -4 due to missed trials in excess of 25%.

The results from Experiments 2-4 provide further support for the hypothesis that people conceptualize causation in terms of forces. Mixed ANOVAs indicated a significant interaction between event type (causal, non-causal) and

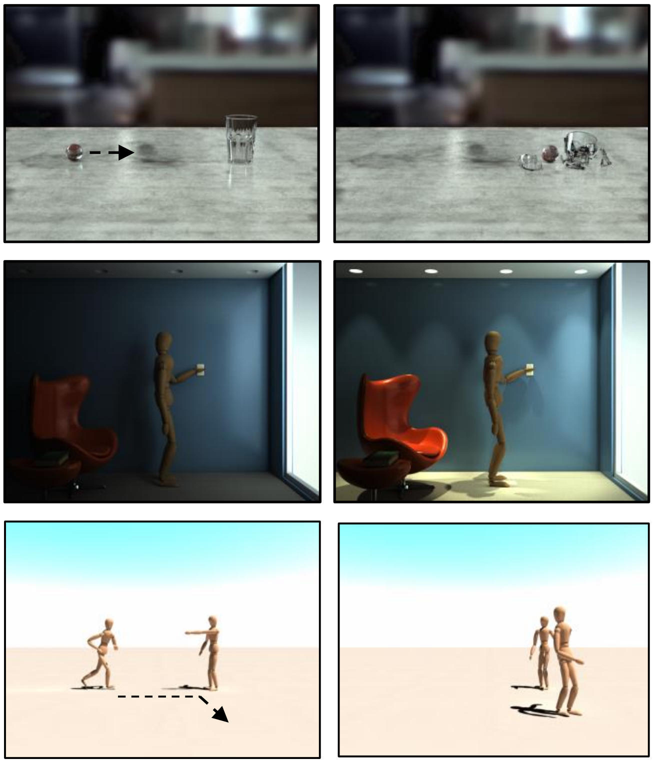

Figure 4. Two frames from the causal animations used in Experiments 2, 3, and 4.

signal type (force, sound, visual) in Experiment 2, $F(2,87) = 3.48$, $p = .035$, $\eta^2 = .074$, Experiment 3, $F(2,87) = 3.38$, $p = .039$, $\eta^2 = .072$, and Experiment 4, $F(2,87) = 3.093$, $p = .05$, $\eta^2 = .066$. These interactions imply that the difference in speed to detect a signal after watching causal versus non-causal events differed across the different types of signals. Specifically, planned comparisons indicated that people were faster to report feeling a force after watching a causal than a non-causal animation in Experiment 2, $t(29) = -2.82$, $p = .009$, $d = .51$, Experiment 3, $t(29) = -2.85$, $p = .008$, $d = .52$, and Experiment 4, $t(29) = -2.32$, $p = .028$, $d = .42$, just as predicted by the causal force hypothesis. Further, additional planned comparisons provided no evidence for differences in people's responses to auditory or visual signals in Experiment 2, $t(29) = -.545$, $p = .59$, $t(29) = .499$, $p = .621$, Experiment 3, $t(29) = -.002$, $p = .999$, $t(29) = -.545$, $p = .59$, or Experiment 4, $t(29) = 0.33$, $p = .742$, $t(29) = -.647$, $p = .523$, The lack of difference when responding to auditory and visual signals implies that the differences found in response to forces were not due to uninteresting factors such as greater predictability or arousal. Further, the lack of difference in the auditory and visual conditions, in contrast to the difference observed in the force condition, suggests that causal events are uniquely associated with the sense of touch.

The full pattern of RT differences is shown in Table 1, which also includes the results from Experiment 1. As can be seen, the pattern was the same across all experiments. The results from Experiments 2-4 suggest that the impression of force is not limited to changes of location. In Experiment 2,

Table 1
*Difference in RT to indicate a force, sound or visual signal after watching a causal versus a non-causal animation in Experiments 1 – 4 in milliseconds with associated pooled SE's*

| | Stimulus type | | |
|---|---|---|---|
| | Force | Sound | Visual |
| Exper. 1: Realistic coll. | **-14.81** (5.0) | **0.213** (3.10) | **-1.69** (2.87) |
| Exper. 2: Shattering | **-9.67** (3.43) | **-1.56** (2.87) | **1.46** (2.92) |
| Exper. 3: Turning on light | **-13.10** (4.62) | **-.007** (3.79) | **-1.70** (3.11) |
| Exper. 4: Social directing | **-12.50** (5.39) | **1.30** (3.92) | **-1.68** (2.6) |

watching a change-of-state primed people's sense of force. The results from Experiment 3 imply that the connection between force and causation is present even in situations in which the mechanism is invisible. The results from Experiment 4 suggest that people conceptualize social influence in terms of forces, which might help explain the existence of phrases such as *peer pressure* and *social force*.

Of secondary interest, the main effect of event type was significant in Experiment 3, $F(1,87) = 4.86$, $p = .03$, $\eta^2 = .053$, and Experiment 4, $F(1,87) = 10.52$, $p < .001$, $\eta^2 = .195$, but beyond that, no other main effects in Experiments 2-4 were significant.

## Experiment 5

In all of the scenarios examined so far, the causation was concrete enough that it could be represented in an animation. In many cases of causation, however, the nature of causation is more abstract, as when we say *Tax cuts cause economic growth* or *Competition prevents inflation*. The results from Experiment 3 and 4, in particular, support the notion that when people see possible cases of causation, they can sense a force, even when the mechanism is unclear or hidden. If people can infer forces in the absence of clear mechanisms, then they may be willing to infer forces merely on the basis of correlational information. Indeed, what may lead people to infer causation from correlation is the impression that forces may be behind the correlation. This possibility was examined in Experiment 5.

### Method

**Participants** Seventy-two Emory University undergraduates participated for course credit or payment.

**Materials** The materials were animations that looked like the display in Figure 5. The left and right circles in the display will be referred to as the "cause" (C) and "effect" (E), respectively. In 50% of the trials, the cause turned solid; 1.5 seconds later, the effect turned solid. In 20% of the trials, the cause did not turn solid, but the effect did. Finally, in the remaining 30% of trials, neither circle turned solid. Based on these frequencies, the probability of the effect given the cause, P(E|C), equaled 1, and the probability of the effect given the absence of the cause, P(E|¬C), equaled .4. These probabilities entail that the probability of the effect given the cause is greater than the probability of the effect in the

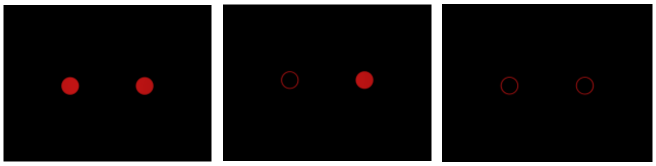

Figure 5. In cause trials (left), both the "cause" and "effect" circles changed color. In non-cause trials, only the "effect" circle (middle) or neither circle (right) changed color.

absence of the cause, that is, P(E|C) > P(E|¬C). Thus, the effect correlated positively with the cause.

**Procedure** As in the previous experiments, participants saw each trial/animation replayed four times in a row. At the end of the fourth animation, participants pressed a button when they felt the haptic controller move. At the end of all of the trials, participants were asked several questions. First, they were asked whether it seemed that the circle on the left sometimes caused the circle on the right to change color. They were also asked to estimate the percentage of time the circle on the right changed when the circle on the left changed, thus providing an estimate of P(E|C), and to estimate the percentage of time the circle on the right changed when the circle on the left did NOT change, providing an estimate of P(E|¬C). Higher estimates for P(E|C) than for P(E|¬C) would imply that participants noticed the correlation between the cause and effect.

Of central importance, half of the participants were given information about the mechanism linking the cause and effect. Specifically, they were told, "The light on the left is linked to the one on the right through a long sequence of circuits." The remaining participants were simply told that they would see a series of animations. It was expected that participants given the mechanism information would tend to infer a causal relationship between the circles, while the remaining participants would not. Of central interest was whether inferring a causal relationship between the circles would affect people's sensitivity to forces.

## Results and Discussion

The data from 9 participants were excluded due to large numbers of missed trials (> 25%).

The results indicate that the correlations sometimes gave rise to impressions of force. As predicted, participants' estimates of the probability of the effect given the cause, P(E|C), was significantly greater than their estimates of the probability of the effect in the absence of the cause, P(E|¬C), in both the mechanism, $t(35) = 3.96$, p < .001, and no-mechanism conditions, $t(35) = 5.04$, $p < .001$, and there was no evidence that the difference in probability estimates in the mechanism condition ($M_{P(E|C)} = 72.5.13$; $M_{P(E|\neg C)} = 45.0$; $D = 27.5$) differed from the difference in probability estimates in the no-mechanism condition ($M_{P(E|C)} = 65.14$; $M_{P(E|\neg C)} = 39.69$; $D = 25.44$), $F(1,70) = .057$, $p = .811$. Thus, the results showed that participants noticed the correlation in both the mechanism and non-mechanism conditions and to the same degree.

A second major prediction was also borne out: participants endorsed the statement that the first circle seemed to cause the second circle to change more often in the mechanism condition ($M$ = 81%) than in the no-mechanism condition ($M$ = 47%), $t(66) = 3.10$, $p = .003$. The question, then, is what makes a correlation seem causal? As it turns out, participants indicated feeling a force faster after seeing causal trails (i.e., when both circles changed color) than non-causation trials (i.e., when only one or none changed color) in both the mechanism, $t(35) = -6.39$, $p < .001$ ($M$s = 348.6 vs. 388) and no-mechanism condition, $t(35) = -3.1$, $p < .001$ ($M$s = 373.5 vs. 388), but the size of the priming interacted with condition. Specifically, the difference in speed was larger in the mechanism condition than in the no-mechanism condition, $F(1,70) = 4.87$, $p = .031$, $\eta^2 = .065$, indicating that there was a greater sensitivity to forces in the condition in which causal inferences were more common.

Interestingly, dividing the participants in the no-mechanism condition according to whether they viewed the two circles as causally connected revealed that sensitivity to force was much greater in those who reported feeling there was a causal connection ($M$s = 356 vs. 383, $D = -26.67$ ms), $t(16)= 3.78$, $p < .01$, than in those who did not feel there was a causal connection ($M$s = 388.62 vs. 392.1; $D = -3.5$ ms), $t(18)=.655$, $p = .521$. This implies that the significant effect of force in the no-mechanism condition was driven by participants who inferred causation between the circles. The results paint a clear picture: most of the participants detected a correlation, but only some of those participants interpreted the correlation as causal. Those who interpreted the correlation as causal also experienced a sense of force.

## General Discussion

The results support the causal force hypothesis—the proposal that the mental representation of causation is associated with the notion of force. In Experiments 1-2, the causal events involved collisions in which one object exerted forces on another. The key finding from these experiments was that seeing causation primed feeling a force. In Experiment 3, people felt forces in response to watching someone turn on a light, suggesting that forces are felt even when the chain of physical interactions is largely hidden. In Experiment 4, seeing a person direct another person triggered a sense of force, indicating that the causal force hypothesis extends beyond the physical realm to social interactions. The results from Experiment 5 provided further evidence for the connection between causation and forces in showing that feelings of force may play a key role in people's interpretations of correlations: in the absence of force, a correlation was just a correlation.

A connection between causation and forces has been observed in at least two other recent studies. In both White (2011) and Hubbard and Ruppel (2013), participants provided ratings of causation and force for a wide range of billiard-ball-type events. The overall finding from these studies was that causation and force ratings mostly followed one another. One situation in which they diverged was when an object A hit an object B and B did not move (Hubbard & Ruppel, 2013). People were willing to give high ratings of force, but were unwilling to say that A caused B to move. This result demonstrates that forces are not sufficient for causation, but it might still be the case that forces are necessary for causation.

The results from Experiment 4 fit nicely with those of Lee and Schnall (2014), who found a link between social power and weight perception. In their experiments, people with lower levels of social power judged the weight of boxes as heavier than those who had higher levels of social power. Together with our results, these findings suggest that people conceptualize social forces in a manner analogous to the way they conceptualize physical forces.

The two sets of findings also point to the potential role of force in the representation of various other kinds of abstract concepts. For example, the notion of *justice* seems to be based on the idea of restoring or maintaining *balance*, a concept that might be tied to the notion of force. Thus, in addition to playing a key role in the concept of causation, the results suggest how the sense of touch may play a foundational role in the representation of other key concepts in higher-order cognition, and how such concepts might ultimately be grounded in perceptual experience.

## Acknowledgments

We thank Tyler Brown, Ted Guio, and Lee Kugelmann for their assistance with stimulus preparation and data collection.

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