MISLOCALIZATIONS OF TOUCH TO THE LOCUS OF A FAKE HAND

by

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Abstract

Space-relevant tactile localizations may be influenced by non-tactile sources of information. This is evident in the fake hand effect wherein observers mislocalize tactile targets delivered to their unseen hand towards a visible fake hand that is positioned next to a pair of distractor lights. The aim of the present study was to use the fake hand effect to explore the factors that influence tactile localizations. First, the effect was quantified by comparing tactile localizations in the presence of the fake hand to those when the observer’s hand instead occupied the normal fake hand location. The effect was quantitatively weaker than one would expect if the tactile targets were mislocalized to the locus of the fake hand (Experiment 1). Surprisingly, the fake hand effect did not depend on direct vision of the fake hand (Experiments 1 & 2), nor was it enhanced by tactile information that was congruent with the fake hand (Experiment 3). The effect, however, was sensitive to the consistency between the orientation of the fake hand and the observer’s hand such that it disappeared when the two were inconsistent (Experiment 4). It was also sensitive to the mapping between the location of the digit stimulated and the type of foot response required (Experiment 5). These results have important implications for the flexibility of one’s body schema.
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Introduction

The human tactile system is often confronted with an important spatial ambiguity to resolve when a tactile stimulus is delivered to the surface of the skin. In addition to determining the location of the tactile event on the body’s surface, it is also often important to know the location of the tactile event with respect to the body’s external surround. Consider, for example, a tactile stimulus delivered to the hand. First, one must correctly recognize where the stimulus was delivered on the body (e.g., to the hand). Then, in order to know where the event occurred in space, one must figure out where the hand is positioned in space (e.g., at one’s side). This thesis will examine several factors that may influence the accuracy and efficiency of tactile localization.

The tactile system provides important body-relevant information. When touched, the mechanoreceptors under the skin are activated and a message signaling the skin stimulation is sent from the spinal cord and the thalamus to the somatosensory cortex region of the brain (Roberts & Wing, 2001). Within this region are groups of neurons that are devoted to particular parts of the body; the spatial layout of these neurons in the brain roughly corresponds to the spatial layout of their receptive fields under the skin’s surface. In order to identify where in the somatosensory cortex each part of the body is represented, Penfield and Rasmussen (1950) carefully stimulated small regions of this area of the cortex in patients undergoing brain surgery and then watched for and recorded the resulting bodily reactions exhibited by them. In this way, Penfield and Rasmussen were able to construct a topographic map linking specific areas of the body to corresponding areas within the cortex (see Figure 1).
Areas of the body that have a greater functional significance, such as the hand and face, are represented by relatively large regions of the somatosensory cortex while other areas like the shoulder are represented by much smaller regions (Roberts & Wing, 2001). The spatial sensitivity of the tactile sensory system is not uniform, rather, the areas of the body that are well represented cortically are the areas that are most sensitive to touch and have a greater number of mechanoreceptors under their skin surface (Cholewiak & Collins, 1991). This fact becomes clear when one looks at the two-point discrimination thresholds for different regions of the body (Sherrick & Cholewiak, 1986, see Figure 1: Sensory homunculus depicting the devotion of specific cortical areas within the somatosensory cortex to different parts of the human body. From Sensation and Perception (5th ed.) (p. 231), by S. Coren, L.M. Ward, J.T. Enns, 1999, New York: Harcourt Brace. Copyright 1950 by Macmillan Publishing Co., renewed 1978 by Theodore Rasmussen. Permission granted.
Figure 2). To obtain these thresholds, either one or two tactile points are applied to the observer's skin (Cholewiak & Collins, 1991). The observer is then asked to report whether they felt a single point or two separate points. In the case where two points are presented, the separation between the two is varied. The threshold is defined as the smallest distance between the two points for which observers are able to report the dual presence. In a region like the thumb (greater neuronal representation), observers are able to identify the presence of two tactile stimuli at relatively small spatial separations. In contrast, in a region like the shoulder (less neuronal representation), the two tactile stimuli must be presented relatively farther apart before the two stimuli are distinguishable from a single point. Tactile recognition accuracy, like localization accuracy, also varies by body loci (Loomis & Lederman, 1986).

Although this tactile system is relatively adept at providing body-relevant information, it is far less capable of providing space-relevant information on its own. Consider once again the example of localizing touch to the hand. Note that the perception of touch is the same whether the hand is held at one’s side, or is held above the head. The tactile system alone cannot easily distinguish between these two possibilities. In other words simply knowing that the hand was touched is not enough information for precise localization of the stimulus. How then does the brain solve this fundamental localization problem?

In addition to the information gained from the tactile sensory system, there are sources of space-relevant information available from the visual and proprioceptive sensory systems (Driver & Spence, 1998; Warren & Rossano, 1991). While vision permits observers to orient their gaze towards the locus of the tactile stimulus, proprioception permits observers to determine where their limbs are in space by relying on information from pressure sensors to determine the position of the joints, the amount of tension in a particular muscle or tendon, or changes in muscle length (Roberts & Wing, 2001). Information from these three sources (tactile, visual, proprioceptive) is thus combined in some way in order to solve the tactile localization problem.

Since the sensory channels often provide redundant information, combining that information is often without incident. However, when spatial or temporal discrepancies or ambiguities exist in the multisensory information received by the brain, interesting sensory illusions can arise. In movie theatres, for example, sound is typically perceived at the location of the movie screen rather than at the true location of the speakers. In this example, the available visual information biases the perceived location of the auditory information.
This effect is commonly referred to as the ventriloquist illusion (e.g., Bertelson & Aschersleben, 1998; Howard & Templeton, 1966). A comparable illusion, referred to as the McGurk effect, is one in which observed lip movements influence speech perception (e.g., McGurk & MacDonald, 1976). Observers who listened to the sound ‘ba’, for example, but who saw lip movements for the sound ‘ga’, actually perceived the sound ‘da’, a combination of the heard and seen sounds.

Consider the case of mystery houses or ‘magnetic hills’, where people standing within the ‘mystery house’ appear to be standing on a dramatic tilt rather than upright, and cars on the ‘magnetic hill’ appear to defy gravity and roll uphill when in neutral gear (Shimamura & Prinzmetal, 1999). Popular tourist attractions, these areas are clear examples of how vision can significantly bias proprioception. These sites work because unbeknownst to the eye, the houses and stretches of road are shifted by about a 25-degree angle from the true horizontal. Since all visual cues to the true horizontal are hidden from the eyes, things look normal, and the brain takes its cues from the available horizontal features in the environment. Thus, rather than relying on signals from proprioception to indicate upright, for example, people tend to rely on vision, with the result that everything within the house, including other people, is seen as tilted rather than upright.

Visual perception itself is susceptible to bias from information in other sensory modalities. Sekuler, Sekuler and Lau (1997), for example, reported an experiment where the presentation of a sound biased observers’ perception of visual motion. That is, the brief onset of a task-irrelevant sound, presented at the point of impact of two identical disks in motion, biased observers to perceive the
ambiguously moving disks as bouncing off of one another rather than passing through. In contrast, when the sound was absent, or was presented at a different point in time than the point of impact, observers were more likely to report that the disks passed through one another. Shams, Kamitani, and Shimojo (2000) reported another sensory illusion wherein the number of auditory beeps that observers heard influenced how many visual flashes they saw. For instance, when a single visual flash was accompanied by multiple auditory beeps, observers reported seeing multiple flashes.

In the case where ambiguous or inconsistent information is available through vision, touch and proprioception, the modality that biases the perception of information in the others is typically the one that is more precise, salient, or more appropriate for the task (Welch et al., 1979; see Welch & Warren, 1980), or the modality to which attention is mainly directed (e.g., Colavita & Weisberg, 1979; Kelso, Cook, Olson, & Epstein, 1975; Posner, Nissen & Klein, 1976). For example, vision is known to be more precise, in most cases, for spatial localization than either proprioception or audition. Thus, when making a spatial localization judgment, observers will tend to rely on vision. This can be the case even when vision is blurred (Fishkin, Pishkin, Stahl, 1975), or when only a minimal view is provided (e.g., fingertip rather than hand for limb localization; Warren & Schmitt, 1978).

There are several empirical examples of visual biases of the perception of touch and proprioception (Hay, Pick & Ikeda, 1963; Mon-Williams et al., 1999; Rock & Harris, 1967). Rock and Harris (1967), for example, reported that when observers view their arm as they point to a central visual target that is displaced by prism goggles, they shift their target-pointing responses in the direction
induced by the goggles. When the goggles are removed, the target-pointing responses are shifted in the opposite direction. These pointing errors are specific to the target hand – the hand used to point when the goggles are on (i.e., they are not obtained with the non-target hand). This latter result suggests that the goggles did not simply change the perceived location of the visual image, which would have similarly affected the target and non-target hand. Rather, the felt position of the target arm must have been altered by the task.

Nielsen (1963) reported an experiment wherein observers were given instructions to first view a straight line on a piece of paper through a small viewing hole, and then to trace the given line at a pace set by a metronome. As far as the observers knew, the view provided was always of their own limb. In reality, however, it was sometimes the experimenter’s hand that they saw. During the initial phase of the experiment, the experimenter matched the observer’s motion (i.e., accurately traced the straight line). In the second phase, however, the experimenter began by following the straight line, but then curved to the right. In response to what they saw the limb do, observers made compensatory limb movements in the opposite direction. Subjective reports collected from observers indicated that they also felt as though their hand was drifting to the right and so tried to correct for this apparent change in location by moving the hand leftward.

Results such as these indicate that observers typically rely on additional information from vision and proprioception in order to determine the space-relevant location of tactile information. This makes them vulnerable to tactile and proprioceptive illusions when the visual information is inconsistent with the other two sources (e.g., Botvinick & Cohen, 1998; Pavani, Spence & Driver, 2000).
Botvinick and Cohen (1998) reported an experiment wherein observers mislocalized brush strokes applied to their out-of-sight hand onto a visible and spatially shifted fake hand. The authors had observers fixate on a fake hand positioned on a tabletop, while the observer’s own left hand was occluded from his or her view (see Figure 3). During the exposure phase, the experimenter used two small paintbrushes to stroke both the observer’s hidden hand and the visible fake hand synchronously. After 10 minutes or so, most observers reported feeling the tactile sensation on their hand as though it arose from the location of the fake hand, and/or they reported that they felt as though their own hand was at the location of the fake hand. In an effort to objectify this experience, the experimenters asked observers to close their eyes, keep their left hand motionless on the table, and to move the index finger of their right hand along the bottom of the table until they believed it to be aligned with the index finger of their left hand. Displacement measures between the two fingers were then taken (both before and after the exposure phase described above). Results revealed larger displacements of the two fingers in the direction of the fake hand following longer exposure periods. Thus, seeing the fake hand influenced the perceived location of the real hand as well as the tactile sensations delivered to it.\[1

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1 Importantly, the authors demonstrated that the synchronicity between the brush strokes on the real and fake hands was critical for obtaining sizable displacement errors.
As intriguing as the illusion described above is, however, there are a couple of limitations with the interpretation of Botvinick and Cohen's (1998) reported data. One, observers were directly asked to report the perceived location of their adapted hand. As a result, it is difficult to know whether observers mislocalized the brush strokes on their hand towards the fake hand, or whether they simply provided responses that they believed were expected of them. To minimize the possibility of such observer response biases, a more indirect measure of tactile and limb localization is needed. Secondly, observers were asked to provide subjective reports of whether the visual information provided (e.g., fake hand) altered perception of their own limb position. The phrasing or ordering of the questions in the brief questionnaire may have biased observers to respond in one way or another, thereby tainting interpretation of the
results. To avoid this, the tactile localization and limb position measures ought to be objective rather than subjective.

Pavani, Spence and Driver (2000) recently reported results similar to those of Botvinick and Cohen (1998), but using methods that circumvented some of the problems described above. That is, their key measure of tactile and limb mislocalizations was indirect (i.e., observers were not asked directly about the perceived location of either), and objective (i.e., did not rely on subjective impressions reported by observers). The two key conditions reported by Pavani et al. (2000) will be referred to here as the No Fake Hand condition (Figure 4A) and the Fake Hand condition (Figure 4B). In both conditions, the authors had observers place their hands beneath a small stand, such that they were out-of-sight, and hold a foam cube in each hand so that a tactile vibrator was positioned under their finger and one under their thumb (see Figure 4A). The task of observers was to use a foot response to indicate, as quickly as possible, the elevation of the target tactile vibration (top or bottom). A matching pair of foam cubes, which held visual distractors in the place of the tactile vibrators, was positioned in view of observers on the stand just above the cubes in the observer’s hands below. One of the visual distractors was presented simultaneously with the tactile target. The elevation of the visual distractor could either be congruent (Figure 4C) or incongruent (Figure 4D) with respect to that of the tactile vibration. In the Fake Hand condition, a fake hand was positioned above each of the observer’s hands and was arranged so as to appear to ‘hold’ the distractor lights (see Figure 4B).
In general, observers were faster and more accurate in localizing the target tactile vibration on congruent trials (Pavani et al., 2000). By computing a difference score between response times on the two trial types (i.e., Incongruent RT minus Congruent RT) the authors were able to index this advantage or Congruency Effect (CE). In the No Fake Hand condition, the CE reported was about 90 ms. Interestingly, this CE jumped to 145 ms in the Fake Hand condition. That is, the CE increased significantly when the fake hands were positioned next to the distractor lights and were aligned with the observer’s hands below.
Further, when the fake hands were misaligned with the observer’s hands by rotating them 90°, the CE dropped back to 85 ms. According to Pavani et al., the distractor lights captured the location of the tactile vibration, and this capture effect was enhanced by the presence of the aligned fake hands. The larger CE in the Fake Hand condition will be referred to here as the *fake hand effect*.

Pavani et al. (2000) report that “the visual information was as if the rubber hands were the participants’ own. Hence, the distractor lights lay close to the position specified by vision for tactile stimulation, even though they remained above the true location of the tactile stimulators and unseen real hands (as specified proprioceptively)” (p. 353). Although they did not say so directly, the authors allude to the idea that if observers had the experience of having their hands at the location of the fake hands, the apparent location of the tactile vibrations would be closer to the distractor lights, and the apparent target-distractor proximity would enhance the effects of the distractors on the perception of the tactile targets.

One limitation to the interpretation of Pavani et al.’s (2000) findings, however, is that the authors did not include a baseline measure that could be used to objectively determine whether, in the presence of the fake hands, observers behave as though the tactile vibrations are felt at the location specified by the fake hands. That is, in order to establish whether this is the case, the authors would need to know how observers behave when the tactile vibrations are actually presented at that location.

The initial goal of the present research was to objectively measure the perceived location of the tactile stimuli in the fake hand effect by introducing a condition wherein the observers held the tactile vibrations in the location
normally occupied by the fake hand. From this, it was possible to index the magnitude of the effect. The effect was then used as the foundation for addressing a number of questions about the factors that contribute to space-relevant tactile localizations. It was possible, for example, to systematically vary the available visual information, and then measure the fake hand effect to determine the extent to which the visual information influenced tactile localizations. It should be noted that since the study of visual-tactile integration is still relatively new, it is difficult to put the fake hand effect in the context of existing theories and predict the outcome of the manipulations introduced here. Thus, for each question addressed in the present research, a variety of possible outcomes were entertained rather than making any specific predictions.

**Overview of Experiments 1-5**

How compelling is the fake hand effect? Do observers actually feel the tactile vibrations at the location occupied by the fake hand? This question was explored in Experiment 1 by comparing the magnitude of the CE across three key conditions: A) when the fake hand was at the level of the distractor lights (Fake Hand condition), B) when the observer’s own hand was at the level of the distractor lights (Real Hand Baseline condition), and C) when the observer’s own hand was below the level of the distractor lights (No Fake Hand condition). If the fake hand effect is so compelling that observer’s feel as though the tactile vibrations arise from the location of the fake hand, then CEs in the Fake Hand condition should be similar to those in the Real Hand Baseline condition and larger than those in the No Fake Hand condition.

Three additional questions of interest regarding the fake hand effect were explored in Experiment 1. First, in order to determine whether the pattern of
responses in the Fake Hand condition was relatively more similar to those in the Real Hand Baseline or the No Fake Hand condition, the spatial separation between the tactile vibration and the distractor light was manipulated. Second, to determine whether the magnitude of the CE in the No Fake Hand condition was influenced by limb visibility, the visibility of the observer's hand was manipulated. Third, to determine whether it was necessary to directly see the fake hand to obtain the fake hand effect, it was compared under conditions of full vision of the fake hand (the standard) with that of partial vision of the fake hand where the fake hand was covered with a cloth and therefore could not be seen directly by the participant.

There were two novel findings in Experiment 1. One, although the fake hand effect reported by Pavani et al. (2000) was measurable, it was also clearly less compelling than one would think given the subjective impressions that Pavani et al. collected from observers. That is, the mean CE obtained when the participant's hand was in the location normally occupied by the fake hand was larger than that obtained when the fake hand was present. Two, vision of the fake hand was not necessary to produce the effect, rather, it was sufficient to have knowledge of the hand's presence reinforced by partial visual cues. This finding was replicated in Experiment 2 even when the cover used to occlude the fake hand was a box, and therefore no longer permitted the hand's shape to be seen. Experiment 2, however, also revealed an important limitation to the above conclusion; the fake hand effect persists when both fake hands are hidden, but it is weaker on the side of a hidden fake hand if that hand is in the context of a second fake hand that is visible at a non-target location.
Experiment 3 tested whether tactile sensory experiences that were consistent with the fake hand effect made the effect more compelling (i.e., increased CEs in the Fake Hand condition relative to the No Fake Hand condition). Observers wore soft plastic kitchen gloves on their hands that were identical to those used for the fake hands. Even with the feel of plastic on their hands, however, the effect remained the same size as that observed in Experiments 1 and 2. This means that the fake hand effect is neither strengthened nor weakened by the presence or absence of consistent tactile information.

In Experiment 4, the rotational posture of the fake hands was manipulated in order to be either consistent with the posture of the observer’s hand (plausible) or inconsistent (implausible). In both cases, the fake hands were aligned with the observer’s hands immediately below. When the posture of the fake hands was inconsistent with that of the observer’s hands, the fake hand effect disappeared. This means that the fake hand effect depends on postural compatibility between the fake hands and those of the participant.

In Experiments 1-4, the mapping between the location of the tactile vibration (top digit vs. bottom digit) and the response of the participant (toe lift vs. heel lift) was assigned in an arbitrary manner. Tactile vibrations localized to the top digit were always assigned to the toe lift and those localized to the bottom digit were assigned to the heel lift. Experiment 5 tested whether the fake hand effect depends in any way on the combinations of the location of the target tactile stimulus (top digit vs. bottom digit), the rotational posture of the observer’s hand (prone vs. supine), and the part of the foot used to indicate the response (toe lift vs. heel lift). The data indicated that the effect was weaker
overall for a top-heel and bottom-toe digit-response mapping. When this particular mapping was combined with a supine observer hand orientation, the effect both weaker and in the reverse direction\(^2\). This latter case indicates that the fake hand effect is not only sensitive to visual posture (i.e., the posture of the fake and the real hand must be compatible), but it is also sensitive to posture when particular response mappings are assigned. In particular, when the observer’s hand is supine, the finger does not map well onto the toe and the thumb does not map well onto the heel. This is especially true when the fake hand is prone (i.e., fake hand posture is rotationally inconsistent with the observer’s hand). It is as though, under these conditions, the observer is compelled to imagine their limb being rotated into the fake hand. This result has important implications for a variety of human-machine interactions.

**Experiment 1**

The goal of Experiment 1 was to evaluate recent claims that tactile stimuli delivered to a hidden limb may be mislocalized to a visible fake hand positioned next to a pair of distractor lights (e.g., Botvinick & Cohen, 1998; Pavani et al., 2000). The behavioral index of these mislocalizations was a larger Congruency Effect (CE) in the presence of the fake hand relative to the CE in its absence. The logic for using this index was that if the target tactile vibrations are mislocalized to the fake hands and thus towards the distractor lights, the apparent proximity between the target vibration and distractor lights will lead to an increased CE.

\(^2\) The term ‘reversed’ is meant to distinguish the effect in this case where CEs are negative and in the direction of being larger for the Inconsistent Fake Hand condition from the standard effect where CEs are positive and larger in the Consistent Fake Hand condition.
(e.g., slower RTs on Incongruent trials, faster RTs on Congruent trials, or a combination of both).

There were four main questions addressed within Experiment 1:

Are tactile vibrations mislocalized to the fake hands?

To make such a judgment, one would first need to establish a baseline CE measure in order to know what magnitude of CE to expect if the target tactile vibrations were at the location normally occupied by the fake hand digits. To do this, a Real Hand Baseline condition was included in the present study wherein the observer’s own hand, and thus the target tactile vibrations, were positioned in the normal fake hand position. It was expected that if the tactile vibrations are mislocalized in the presence of the fake hands (Fake Hand condition), then their apparent location should be at the same location as the tactile vibrations in the Real Hand Baseline, and thus, the resulting CEs should be the same magnitude in the two conditions. That is, the magnitude of CEs in the Fake Hand condition should be comparable to CEs in the Real Hand Baseline condition where the tactile vibrations are actually at the location that is specified by vision of the fake hand in the Fake Hand condition. This is in contrast to the CEs in the No Fake Hand condition where the tactile vibrators are vertically separated from the distractor lights.

Are the dynamics similar for a fake versus real hand?

Regardless of the absolute magnitude of CEs in the Fake Hand versus Real Hand Baseline conditions, it is equally important to know whether similar patterns of response are generated in the two conditions following a given manipulation. For instance, previous research indicates that tactile target processing is disrupted more by near than by far distractors (Driver &
Grossenbacher, 1996; Macaluso, Frith & Driver, 2000), even when other factors are controlled (e.g., distance of distractor from eye or ear; e.g., Driver & Spence, 1994; Spence, Ranson, & Driver, 2000). By measuring the CEs at multiple target-distractor horizontal separations and comparing the response patterns across conditions, it is possible to determine whether the pattern generated in the presence of the fake hand (Fake Hand condition) is more similar to the case where the observer's own hand is at the location specified by vision (i.e., Real Hand Baseline condition), or at the location specified by proprioception but below that of vision (i.e., No Fake Hand condition). Evidence for the former would support the notion that observers behave, at least to some degree, as though the visible fake hand were their own.

Are CEs influenced by viewing the limb in the No Fake Hand condition?

In the No Fake Hand condition of the Pavani et al. (2000) study, the observer's own hands were hidden from view, and only the distractor lights and the central feedback cube were visible. Previous research suggests that vision of a limb can significantly influence the perception of unseen tactile stimuli delivered to the limb (di Pellegrino, & Frassinetti, F., 2000; Kennett, Taylor-Clarke, & Haggard, 2001; Làdavas, Farnè, Zeloni, & di Pellegrino, 2000; Pierson et al., 1991), even when the view is given by a monitor and observers see their own limb indirectly (Tipper et al., 1998; 2001). It is possible that CEs in the No Fake Hand condition would increase if observers were permitted to see their limbs. On the other hand, there is some evidence to suggest that the view that observers had of the location just above the hidden limbs might be sufficient to benefit target localization (Newport, Hindle, & Jackson, 2001), and thus seeing the limb might not alter CEs. Yet another possible pattern of results is that CEs
would decrease if the observer's hand were visible. This might be the case if the vertical separation between targets and distractors is more pronounced when the hand is visible (i.e., spatial separation would reduce the effectiveness of the distractors). To address the question of whether limb visibility influences the magnitude of the CE in the present experiment, the observer's limbs in both the No Fake Hand and the Real Hand Baseline conditions were visible on half of the trials, and hidden from view on the remaining trials.

Is partial vision of the fake hand sufficient for the effect?

Thus far, the fake hand effect has only been tested under conditions where the fake hand is in complete view of observers. The question remains then as to whether the fake hand effect would persist when the observers know that the fake hand is present, but are no longer permitted to see it. To test this, the visibility of the fake hand was manipulated such that on half of the trials in which it was present it was visible, and on the remaining trials it was hidden from view under a black cloth. It was expected that if partial vision of the fake hand is sufficient for the effect, CEs should be of the same magnitude whether the fake hand is hidden or visible. In contrast, if a completely visible fake hand is critical for the effect, then relatively large CEs should only be obtained when the fake hand is visible, but not when it is hidden.

Methods

Participants: Forty-two undergraduate observers from the University of British Columbia Psychology subject pool participated in a 45-minute experimental session in return for partial course credit. All had normal or corrected-to-normal vision. All observers were naïve to the purpose of the
experiment and were fully debriefed upon completion. Further participant information is provided in Table 1.

Procedure: The task of observers was to make a speeded forced-choice tactile localization judgment. The target was a tactile vibration applied to either the finger or thumb of the observer's right hand. Location responses were made via two foot-pedals, one positioned under the toes of the right foot, and the other under the heel. At rest, both pedals were depressed\(^3\). To indicate that the tactile vibration location was at the finger, observers released the pedal under their toes briefly and then rested. To indicate that the tactile vibration location was at the thumb, they briefly released the pedal under their heel, and then rested. Observers were instructed to ignore the simultaneous onset of a distractor LED while maintaining center fixation and attending to the target tactile vibration. Observers took short breaks between each experimental block of trials.

Apparatus: Figure 5 includes illustrations of the basic experimental setup for each of the three conditions, including samples of the visibility manipulation: visible (Figure 5A) and hidden (Figure 5B). Also included in Figure 5 is an example of each of the three target-distractor separations (none, small, and large). A chin rest was centered on a table. It was used to stabilize the position of the observer's head at a distance of 47 cm from a red central fixation LED. Cardboard boundaries were constructed and secured on the left and right sides.

\(^3\) This took little-to-no effort on the observer's part. The mere weight of the observer's foot at rest was all that was required to depress the pedals. Similarly, little effort was needed to release the pedal. The toes or heel had to be raised just enough so that the pedal was no longer completely depressed. Note that this did not require the toes or heel to clear the pedal.
of the chin rest, and were used to maintain the position of the observer's forearms.

Figure 5. Mean CEs (in ms) for Experiment 1 as a function of Condition (No Fake Hand, Fake Hand, Real Hand Baseline) and Target-Distractor Separation (None, Small, Large) for (A) Visible and (B) Hidden limbs.
The two target tactile vibrators were Oticon-A bone conduction vibrators of 100 Ohms. They were positioned in the upper and lower left hand corners of a foam cube. A TENMA function generator was used to deliver each tactile target. To mask the sound of the vibrators, white noise was played through a pair of headphones worn by observers. Two yellow distractor LEDs were positioned in the upper and lower right hand corners of a second foam cube, which was placed on top of a tall strip of foam running horizontally from the back of one set of forearm boundaries to the other.

The fake hand, used at different points during the experiment, was constructed using a right-handed pink soft plastic dishwashing glove stuffed with cotton batting. When the fake hand was present, it rested on a sheet of black corkboard that was positioned over top of the forearm boundaries. Note that whenever the fake hand was present, this meant that the observer’s own hands were under the corkboard and thus out of sight.

Observers made their responses by releasing one of two footpedals as quickly and as accurately as possible. When they localized the tactile vibration to their finger observers were instructed to release the pedal under the toes, and when they localized the tactile vibration to their thumb they were instructed to release the pedal under the heel.

**Stimuli:** To produce a visual distractor, one of the two LEDs was flashed three times for a duration of 50 ms each time, with each flash separated by a 50 ms ISI. To produce the tactile target, three 50 ms 200-Hz sine-wave signals separated by 50 ms ISIs were sent from one of the two tactile vibrators. The target and distractor were always presented simultaneously. Target and
distractor locations were random with the constraint that each location was selected from equally often. Whenever observers made an error in response (including a failure to provide a response), a yellow LED positioned two centimeters below the fixation LED was flashed six times for 50 ms each time (50 ms between each flash).

**Design:** Each observer completed two practice blocks of 15 trials at the beginning of the experiment. In the first practice block, only tactile stimuli were presented (i.e., no distractor lights). The second practice block consisted of both visual and tactile stimuli. Following the practice blocks, observers participated in six experimental blocks of 96 trials (576 trials in total). Correct response times (RT) and mean percentage errors were recorded.

Observers were randomly assigned to one of three conditions: No Fake Hand (n = 14), Fake Hand (n = 14), or Real Hand Baseline (n = 14). In all three conditions, the observer held the vibrator cube between the index finger and thumb of their right hand. The No Fake Hand and Fake Hand conditions were similar to those tested by Pavani et al. (2000) wherein the observer’s right hand was always below the position of the distractor cube. In the Fake Hand condition, a sheet of corkboard was spread over the top of the forearm boundaries thus hiding the observer’s hands below, and the fake hand was positioned on top of the corkboard on the right hand side. Note that this positioning of the fake hand meant that it was always aligned vertically with the observer’s hand below, and it was aligned horizontally with the distractor cube. A foam cube was positioned between the index finger and thumb of the fake hand to enhance the similarities with the observer’s hand (refer to the Fake Hand condition pictured in Figure 5). On trials where the distractor cube was
positioned beside the fake hand, the fake index finger rested next to the upper distractor light and the fake thumb next to the lower distractor light. The Real Hand Baseline condition was the key comparative condition introduced in the present study. It was similar to the No Fake Hand condition with the one exception that the height of the observer’s hand was raised to the level of the distractor cube by having observers rest their arm on a thick strip of foam.

Three within-observer factors were manipulated: Congruency of target-distractor elevations, horizontal Separation between the distractor cube and target cube, and the Visibility of the observer’s hand or of the fake hand (when present). Each of these factors is described in turn below.

Target-distractor elevations were either congruent or incongruent (Congruency factor). Congruent trials, in this case, consisted of an upper LED paired with a top-finger vibration, or a lower LED paired with a bottom-thumb vibration. Incongruent trials, in contrast, consisted of an upper LED paired with a bottom-thumb vibration or a lower LED paired with a top-finger vibration. Each target-distractor pair occurred equally often in each block.

The horizontal separation between the LED distractor cube and the target tactile vibration cube was manipulated by moving the distractor cube in a leftward direction away from the tactile vibration cube. There were three possible separations: none (0 cm apart, distractor cube at right), small (15 cm apart, distractor cube at center), or large (30 cm apart, distractor cube at far left). Note that within any condition, the position of the target tactile vibration cube remained constant in that it remained on the right side. Thus, the distractor cube was always to the left of the target cube, and only the position of the distractor cube was altered. This meant that when the fake hand was present, it remained
on the right side above the location of the observer's hand below, and the
distractor lights were either beside the fake hand, a small distance away, or a
larger distance away.

The visibility of the observer's limbs in the No Fake Hand and Real Hand
Baseline conditions, and the visibility of the fake hand in the Fake Hand
condition were manipulated such that they were visible on half of the trials, and
hidden on the remaining trials. The sheet of corkboard was used to hide the
observer's hand in the No Fake Hand condition, while a black cloth was used to
hide the fake hand and the observer's hand in the remaining two conditions.

The two within-observer factors, Separation (3 levels) and Visibility (2
levels), were blocked resulting in 6 blocks in total. The order of blocks was
randomized. Condition (3 levels) was a between-observer factor. A breakdown
of the trial types is presented in Table 2.

Results

On each trial, target localization response times and mean percentage
errors were recorded. It should be noted that for all of the experiments that
follow (1-5), observers were excluded if either their average RTs were longer
than 1200 ms, or they had fewer than 75% correct responses in any experimental
condition.

Only trials where observers made correct localization responses were
included in the RT analyses. The RT Congruency Effect (CE) was calculated for
each condition by finding the difference between the mean RT on Incongruent

\[ CE = \text{Mean RT}_{\text{Incongruent}} - \text{Mean RT}_{\text{Congruent}} \]

Data was collected on a total of 137 observers throughout experiments 1-5. Of
those, 12 had to be excluded for not meeting the RT or Accuracy criteria
described above.
trials minus the mean RT on Congruent trials. The analyses and discussion were mainly focused on the CE results for two reasons. First, the CE measure is a convenient summary measure as its magnitude is directly indicative of the extent to which the onset of the LEDs interfered with the speeded responses to the tactile vibrations. That is, the larger the CE, the more effective the LED as a distractor. Second, the relative magnitude of the CE is indirectly indicative of the perceived separation between the tactile vibrations and the distractor lights, where the larger the CE, the smaller the perceived target-distractor separation.

The mean percentage errors were also analyzed as CEs (Incongruent Errors – Congruent Errors) and this pattern of data was compared to that of the CEs for RTs. If either there were no significant effects observed in the Error CE data, or if the same pattern of data was found across conditions in both RT CEs and Error CEs (e.g., the larger RT CEs paired with the larger error CEs), then speed-accuracy tradeoffs were eliminated as a concern. In the event that opposing patterns were observed (e.g., the larger RT CEs paired with the smaller error CEs), speed-accuracy tradeoffs had to be considered as a possibility.

In addition to these main analyses of interest using the CEs, identical analyses were computed using the mean Correct RT and mean Percentage Error data. This was done to ensure that the pattern of results observed from the CEs, which are difference scores, was similar to that for the means. These latter analyses are presented for each Experiment in an Appendix. Since the results were always consistent with the RT and Error CE analyses, they will not be discussed further.

Both the RT CEs and Error CEs were subjected to analyses of variance (ANOVA) involving within-observer factors of Separation (None, Small, Large)
and Visibility (Visible, Hidden), and the between-observer factor of Condition (No Fake Hand, Fake Hand, Real Hand Baseline). Significant three-way interactions were followed up using Simple Interaction Effects, while significant two-way interactions were followed up using Simple Effects testing. Significant main effects were followed up using Least Significant Difference (LSD) tests.

As pictured in Figure 5, there were several notable findings in the present study. First, when the limbs were visible and there was no separation between targets and distractors (see the solid black bars in Figure 5A), there were significant differences in the magnitude of the CEs across conditions, with the CE being the largest in the Real Hand Baseline condition, and smallest in the No Fake Hand condition. This suggests that although tactile targets were being mislocalized to the fake hand when it was present, the fake hand effect was not of equal strength to the presence of the observers’ own limbs in the same location. For the small and large target-distractor separations, the CEs were of similar magnitude across conditions.

Second, the CEs tended to decrease with increasing target-distractor separation for all conditions except the No Fake Hand condition. The fact that similar patterns were observed in the Fake Hand and Real Hand Baseline conditions suggests that there are some similarities between the fake hand and a real hand despite differences in the absolute magnitude of CEs.

Third, hiding the limbs from view had very little impact on the magnitude of the CEs relative to when the limb was visible (compare Figure 5B to 5A). There was one exception to this. When there was no target-distractor separation (see solid black bars in Figure 5), CEs were larger in the No Fake Hand condition when the hand was hidden (Figure 5B) than when it was visible (Figure 5A).
This finding suggests that the visual cues to the vertical separation between targets and distractors when the observer's hands were visible in the No Fake Hands condition may reduce the influence of the distractor lights on tactile localization.

When the RT CEs were used as the dependent variable, both the main effect of Condition \( F(2, 39) = 4.29, p < .05, \text{MSE} = 8325 \), and that of Separation \( F(2, 78) = 19.13, p < .001, \text{MSE} = 1562 \) were significant. These main effects were tempered by a significant two-way interaction of Condition x Separation \( F(4, 78) = 5.95, p < .01, \text{MSE} = 4259 \), and a significant three-way interaction of Condition x Separation x Visibility \( F(4, 78) = 2.59, p < .05, \text{MSE} = 1400 \). The three-way interaction was first broken down into its component Condition x Separation interaction at each level of Visibility.

When the limbs were visible (see Figure 5A), the Condition x Separation interaction was significant, \( F(4, 78) = 7.99, p < .01, \text{MSE} = 2984 \). This interaction was followed up by first testing the main effect of Condition at each level of separation. The main effect of Condition was significant only when there was no target-distractor separation \( F(2, 39) = 12.75, p < .001, \text{MSE} = 5371 \), where the CE was largest for the Real Hand Baseline condition (189 ms), smaller for the Fake Hand condition (128 ms), and smallest for the No Fake Hand condition (50 ms), all paired comparisons were significant at \( p < .05 \). Secondly, the main effect of Separation was tested for each of the three conditions. For the Real Hand Baseline condition, the main effect and all paired comparisons were significant, all \( p \)'s < .05. CEs were largest when there was no target-distractor separation (189 ms) and decreased for the small separation (95 ms) and decreased further for the large separation (44 ms). For the Fake Hand condition, the main effect of
separation was significant, $F(2, 26) = 5.53, p < .05, \text{MSE} = 3667$. Least significant difference testing revealed that CEs tended to be larger when there was no separation (128 ms) than when there was either a small separation (82 ms; $p < .06$) or a large separation (52 cm; $p < .05$), but the comparison between CEs at the latter two separations did not reach significance ($p > .05$). Finally, the main effect of Separation approached significance for the No Fake Hand condition, $p < .06$. Follow-up tests indicated that CEs tended to be larger at the small separation (85 ms) than when there was no separation (50 ms), $p < .05$. The comparisons with the large separation (56 ms) did not reach significance, $p's > .05$.

When the analysis was limited to the data for trials where the limbs were hidden (see Figure 5B), the interaction between Condition and Separation did not reach significance, $p > .10$.

The overall three-way interaction was also broken down by computing the simple interaction of Condition x Visibility at each level of Separation in order to determine the effect of covering the hand on CEs within each condition. This interaction approached significance when there was no target-distractor separation [$F(2, 39) = 3.05, p < .06, \text{MSE} = 2108$], but did not reach significance at either the small or large target-distractor separations, $F's < 1$. Follow-up tests for the former revealed that the effect of Visibility was significant only for the No Fake Hand condition where CEs were larger when the hand was hidden (81 ms) than when it was visible (50 ms), $F(1, 13) = 4.54, p < .055, \text{MSE} = 1494$. Remaining $p's > .05$.

When the overall analysis as that reported above was computed using mean Error CEs as the dependent variable, only the main effect of Separation was significant, $F(2, 78) = 6.98, p < .01, \text{MSE} = 41$. Least significant difference
testing revealed that CEs were larger when there was no target-distractor separation (7%) than either the small (4%) or large (4%) separations (p's < .01), which were not significantly different from one another, p > .20. The CEs that were significant were in the same direction as the RT CEs suggesting that speed-accuracy tradeoffs were not a concern (e.g., larger RT CEs and Error CEs when there was no target-distractor separation).

Discussion

There were four main findings in the present study. The implications of each are discussed in turn below.

Larger CEs in the Real Hand Baseline versus Fake Hand condition:

This finding implies that the experience of the fake hand effect is not identical to the experience observers have when the tactile vibrations are presented at the location of the fake hand. That is, the felt location of touch appears to be different when vision alone indicates that the tactile vibrations are beside the distractor lights (Fake Hand condition) compared to when vision and proprioception indicate the spatial alignment between targets and distractors (Real Hand Baseline condition). This is an important new finding, as it provides an objective indication that the fake hand effect may be less compelling than the observer’s subjective impressions would lead one to believe. It is, however, consistent with reports from the earlier multimodal discrepancy literature that indicates that the visual bias of proprioception is rarely 100%, rather, it tends to average around 75% (see Welch & Warren, 1980).

CEs decrease with increases in target-distractor separation:

This pattern was observed in both the Fake Hand and Real Hand Baseline conditions but not in the No Fake Hand condition. This is consistent with the
idea that the fake hand is similar to a real hand for observers (note that this can be the case even though the absolute CE data shows that responses in the presence of the fake hand are weaker than those obtained with the real hand).

It is interesting to note that in these two conditions CEs were largest overall when there was no target-distractor separation despite the fact that at the small separation, the distractor lights were located at the center of gaze. If seeing the distractors were the key factor, one would expect that it would be at this location that the lights would have the greatest impact on target localization responses. That they had their greatest impact when they were next to the target vibrations and away from the center of gaze indicates that it is the spatial proximity between the targets and distractors that is of most importance. This target-distractor separation effect is consistent with earlier reports suggesting that the greater the discrepancy in information within the visual and proprioceptive sources, the less evidence for visual bias (Over, 1966; see Welch & Warren, 1980).

The fact that the above separation pattern was not observed in the No Fake Hand condition indicates that the vertical separation between targets and distractors is enough to weaken the magnitude of the CE. In fact, it was only in this condition that CEs tended to be higher at the center of gaze (small separation) than when there was no separation between targets and distractors. Further, since the separation effect was present in the Fake Hand condition, it suggests that the fake hand must have successfully bridged the vertical target-distractor separation that was apparent in the No Fake Hand condition.
Little-to-no effect of limb visibility on CEs:

The only condition in which there was an effect of visibility was the No Fake Hand condition wherein CEs were smaller when the hand was visible relative to when it was hidden. Since this effect of visibility was limited to the No Fake Hand condition, it seems likely that making the observer’s hand visible in this case emphasized the vertical separation between the tactile vibrations and the distractor lights thereby reducing the CE.

Partial vision of the fake hand is sufficient for the effect:

As noted above, hiding the fake hand in the Fake Hand condition did not significantly change the magnitude of the CEs. That is, the CEs tended to be larger in the Fake Hand condition than in the No Fake Hand condition whether the hands were visible or not. These results are somewhat of a surprise as they suggest that directly seeing the hand is not critical for tactile mislocalizations, and knowing that the fake hand is present, and having partial visual information to reinforce that, is sufficient to influence responses.

The experimental design used in Experiment 1 was a modified version of that used by Pavani et al. (2000). The modifications were necessary in order to incorporate the target-distractor separation manipulation used. One drawback to modifying the Pavani et al. (2000) design, however, is that direct comparisons are more difficult to make between the results of their experiment and the present one. For this reason, we reverted back to the Pavani et al.’s original design in Experiment 2 such that tactile vibrations were presented to either the observer’s right or left hands, and distractor lights were either presented to the right or left sides of fixation.
In Experiment 2, a more stringent test of whether partial vision of the fake hand's presence is sufficient for the effect was applied by introducing two different manipulations. One, a box cover as opposed to a cloth cover was used to hide the hand, the difference being that the former eliminated hand shape information while the latter did not. It was expected that if a placeholder reminder of the fake hand’s presence is sufficient for the effect, then hiding the hand under the box will have no effect on the magnitude of the CEs. In contrast, if partial vision of the fake hand’s presence is not sufficient, but the accessibility of hand shape information contributed to the results in Experiment 1, it was expected that CEs would be smaller when hidden under the box cover than when visible. Additionally, Experiment 2 was designed to test whether partial vision of the fake hand would continue to be sufficient for inducing the effect if there were a second fake hand that was uncovered and within the observer’s view. One possibility is that the effect will be present for both the hidden and visible fake hand. Another, more interesting possibility, is that the available visual limb information will compete with the hidden limb information, and the effect will be influenced in some way by this competition.

**Experiment 2**

There were two main goals of Experiment 2. The first was to determine whether observers would continue to mislocalize tactile targets when both fake hands were hidden under box-covers that eliminated hand shape information. Three possible results were considered at the outset. One possibility is that once the shape of the fake hand is no longer visible, observers will behave as though the fake hand were absent (i.e., CEs for the Fake Hand condition will be similar
to those in the No Fake Hand condition). This result would indicate that seeing the features of the hand (e.g., shape) is an important part in generating mislocalizations, and that the conclusions drawn in Experiment 1 that partial vision of the fake hand is sufficient for mislocalizations would have to be modified.

A second possibility is that observers will continue to mislocalize tactile targets to the fake hand, but will do so to a lesser degree than when the fake hand is visible (i.e., CEs will be smaller for the hidden versus visible fake hand but larger than CEs when the fake hand is absent). A result such as this would indicate that feature information about the hand contributes to the mislocalizations (i.e., CEs are larger when shape information is available), but is not necessary for them.

A third possibility is that simply knowing that the fake hand is present is sufficient for mislocalizations (i.e., CEs are the same magnitude for a hidden and visible fake hand). This is the more interesting possibility, as it would highlight that the effect is not a purely visual or stimulus-driven one but rather it may be elicited by top-down information and imagery based on partial vision.

The second goal of the present study is to determine whether mislocalizations to a hidden fake hand change as a function of the visible presence of a second fake hand. It could be the case that the effect is obtained as before with both the hidden and visible hand. Another possibility, however, is that the effect is weaker on the side of the hidden fake hand than on the side of the visible fake hand. This latter outcome would indicate that the more detailed visual information carries more weight than does partial visual information when both are available.
The design of Experiment 2 was similar to that of Pavani, Spence and Driver (2000). Tactile targets were now held in both the left and right hands, and in the Fake Hand condition, a fake hand was positioned above each of the observer’s hands. In the No Fake Hand condition, the fake hands were absent and only the distractor lights and central feedback cube were visible. With this design, it was possible to present tactile targets and visual distractors to either the right or left side of space. Most importantly, it was possible to manipulate the visibility of both fake hands, or the visibility of just a single fake hand. In this latter case hiding only a single fake hand meant that the other fake hand was visible. This effectively places the hidden and visible hand in direct competition with one another. This manipulation provided an opportunity to test the reliability of the finding that a partial visual reminder of the fake hand’s presence is sufficient for tactile mislocalizations.

Methods

Participants: Thirteen undergraduate students at the University of British Columbia participated in the one-hour experimental session for partial course credit. Personal descriptive information is provided in Table 1. All observers reported normal or corrected-to-normal vision. Observers were naïve to the purpose of the experiment and were fully debriefed upon completion.

Apparatus: Similar to that used in Experiment 1. Observers laid their arms on the surface of a table (within arm boundaries on either side), and underneath a smaller stand. For this experiment, they held a foam cube in each hand. Each foam cube contained a pair of tactile vibrators as described in Experiment 1. On the surface of the smaller stand, two foam cubes were positioned so that one was aligned above each tactile foam cube held below.
These visible cubes held pairs of distractor lights, again these were as described in Experiment 1. In four of the five conditions, a pair of fake hands (constructed as before from a pair of soft pink kitchen gloves stuffed with cotton batting), were positioned so as to appear to 'hold' the distractor lights on their respective sides. To hide either or both of the fake hands, a box cover was placed over the top of the hand. In doing so, hand shape information was eliminated. On the remaining block, the fake hands were absent. The five conditions were completed in random order.

**Stimuli:** Same as that used in Experiment 1, with the exception that there were now four possible target locations and four possible distractor light locations. Locations were randomly selected with the constraint that all locations were selected from equally often, and that there were an equal number of congruent and incongruent trials, and an equal number of same and opposite side target-distractor presentations.

**Design:** Observers participated in three training sessions of 15 trials each, followed by five experimental blocks of 96 trials. All factors were run as within-observer factors. Observers participated in five randomly ordered Fake Hand Conditions: No Fake Hand, Both Visible, Both Hidden, Left Hand Hidden, and Right Hand Hidden. Note that in all conditions, the observer's hands were always underneath the small stand, below the level of the distractor lights. In the No Fake Hand condition, there were no fake hands on the stand, only the distractor light cubes and the feedback cube in the center were visible. In the remaining conditions, both fake hands were present and were positioned so as to appear to 'hold' the distractor lights. In the Both Visible condition, both fake hands were in view, while in the Both Hidden condition, both fake hands were
hidden beneath box covers. In the Left Hand Hidden and Right Hand Hidden conditions, the left or right fake hand, respectively, was hidden from view underneath a box cover while the remaining hand was visible.

**Procedure:** Same as that in Experiment 1.

**Results**

RT CEs and Error CEs were again the dependent measures of interest. Significant effects were followed up using the same procedures as indicated in Experiment 1. All factors were within-observer factors and included Condition (No Fake Hand, Visible, Hidden, Left Hand Hidden, and Right Hand Hidden), and Target-Distractor Side (Same, Opposite).

There were two main findings. One, when both fake hands were hidden from view using box covers, CEs were of the same magnitude as those observed when both fake hands were visible (see Figure 6). This suggests that observers were still inferring the presence of the fake hands, despite the fact that they were covered and their shape disguised. In other words, observers still mislocalized tactile targets to the fake hands when both were hidden. Note that the CEs in these two conditions were larger than those found when the fake hands were absent.
A. Same

B. Opposite

Figure 6. Mean CEs (in ms) for Experiment 2 as a function of Fake Hand Condition (No Fake Hands, Both Visible, Both Hidden, One Hidden – Touch on Hidden Side, One Hidden – Touch on Visible Side) for (A) Same and (B) Opposite target-distractor presentations.

Two, when only one of the fake hands was hidden and the other was visible, CEs were significantly larger when targets and distractors were presented to the side of the visible fake hand than when they were presented to the side of the hidden fake hand (see Figure 6). This is a very different result from that obtained when either both fake hands are visible or both fake hands are hidden. This suggests that when there is both a visible and a hidden fake hand in competition observers are less likely to infer the presence of the hidden hand.

Two main analyses were computed. First, a repeated measures ANOVA was computed using RT CEs as the dependent measure, and Condition (No Fake Hands, Both Visible, Both Hidden) and Target-Distractor Side (Same, Opposite) as within-observer factors, refer to Figure 6. Both the main effects of Condition
and Distractor Side were significant [F (1, 25) = 23.65, p < .01, MSE = 12367], as was the interaction [F (2, 50) = 5.0, p < .05, MSE = 6038]. The interaction was examined more closely by looking at the main effect of Condition separately for each target-distractor type (i.e., same and opposite side presentations; see Figure 6A and 6B, respectively). The main effect of Condition was significant only for same-side target distractor presentations, F (2, 50) = 5.44, p < .05, MSE = 10422. CEs were smallest in the No Fake Hands condition (77 ms) than either the Both Visible (169 ms) or Both Hidden conditions (137 ms), p's < .05. CEs in the latter two conditions did not differ significantly from one another, p > .20.

The same analysis as that above was computed using Error CEs as the dependent measure. Only the main effect of Target-Distractor Side was significant, where CEs were larger when targets and distractors were presented to the same side (6.1%) versus the opposite side (1.8%) of fixation, F (1, 25) = 9.03, p < .01, MSE = 79. No other effects were significant, F's < 1. Speed accuracy tradeoffs were not a concern as the error rates were either the same across conditions or their pattern resembled that found in the RT CEs.

The second analysis focused on the two conditions where either the left or right fake hand was hidden, Left Hand Hidden and Right Hand Hidden, respectively. The data were organized into two factors that each had two levels, Side of Touch (Hidden, Visible) and Distractor Side (Same, Opposite). The factor Side of Touch referred to the side of space that the tactile stimuli was delivered to, that is, whether it was the side of the hidden fake hand or that of the visible fake hand. Distractor Side referred to the side of space that the distractor light
was delivered to, that is, whether it was the same side as the tactile stimulus or the opposite side.

A repeated measures ANOVA was computed on the RT CEs using both Side of Touch and Distractor Side as factors (refer to the two rightmost bars in Figure 6A and 6B). The main effect of Distractor Side was significant, $F(1, 25) = 18.72, p < .01, \text{MSE} = 9750$. This was tempered by a significant Side of Touch x Distractor Side interaction, $F(1, 25) = 5.45, p < .03, \text{MSE} = 7968$. To better interpret the interaction, the simple main effect of Side of Touch was examined separately for same and opposite side target-distractor presentations. The simple main effect of Side of Touch was significant only when the distractor was presented to the same side of space as the target. When this was the case, CEs were significantly larger for targets presented on the side of the visible fake hand (182 ms) compared to the side of the hidden fake hand (106 ms), $F(1, 25) = 7.33, p < .05, \text{MSE} = 10278$.

When the above analysis was repeated using mean error CEs as the dependent variable, a similar pattern of results was observed, and speed-accuracy tradeoffs were eliminated as a concern. The main effect of Distractor Side was significant, $F(1, 25) = 14.33, p < .001, \text{MSE} = 54$. This was tempered by a significant Side of Touch x Distractor Side interaction, $F(1, 25) = 6.09, p < .05, \text{MSE} = 86$. The main effect of Side of Touch was examined separately for Same and Opposite target-distractor presentations. With same side target-distractor presentations, error CEs tended to be larger for targets presented to the visible (12%) versus hidden (7%) fake hand, $F(1, 25) = 3.07, p < .10, \text{MSE} = 111$. With opposite side target-distractor presentations, error CEs tended to be larger when targets were presented to the hidden hand (6%) than the visible hand (2%), $F(1,$
This last result, although not significant in the RT CEs, is still consistent with the pattern observed there. With the exception of this last result, the error CEs were either the same across conditions or their pattern was the same as the RT CEs, and thus speed-accuracy tradeoffs were not a concern.

Discussion

In Experiment 2, there were two main findings. Each will be discussed in turn below.

CEs are similar whether both fake hands are visible or hidden:

Observers continue to infer the presence of both fake hands even when they are hidden under box covers. In other words, when observers are aware of the presence of the fake hands, but are unable to see them directly, they continue to mislocalize tactile targets to them. This implies that the fake hand effect can be elicited by partial visual information that reinforces that the fake hands are present.

CEs are larger on the side of a visible versus hidden fake hand:

This finding differs from that found when either both fake hands were visible, or both fake hands were hidden, neither of which differed from one another. It suggests that when there is potential for competition between a visible and hidden hand, observers will weight the visual information more heavily so that full visual cues influence tactile localizations more than partial cues. This is an important finding as it indicates flexibility in the observer’s usage of the visual information that is available when there is a discrepancy between the seen and felt limb locations. In the absence of any other visual
information, observers will respond to a hidden limb as though it were visible, but fail to do so when there is more salient visual information available.

Experiments 1 and 2 provide further empirical support for the idea that tactile targets can be mislocalized towards a fake hand. The novel contribution of the present studies is the finding that tactile targets are not mislocalized to the extent that the tactile vibrations are felt at the fingers of the fake hand, or to the extent that observers behave as though their own hands are at the location specified by vision of the fake hands. These results make a quantitative contribution to the subjective reports collected by Pavani et al. (2000), which indicate most observers feel “as if the rubber hands were my hands”, or “as if I was feeling the tactile vibration in the location where I saw the rubber hands”, or even that it “seemed as if the lights were near to my real hands” (p. 357). In particular, the present results imply that the experience is only about 70% of the full possible strength.

One possible explanation for this apparent discrepancy in results from qualitative versus quantitative measures is that the observers tested in Experiments 1 and 2 did not wear gloves on their hands to match the fake hands whereas observers tested in Pavani et al. (2000) did. That is, it may be that feeling the soft plastic on their hands, as well as seeing the soft plastic fake hands, enhanced the experience of tactile mislocalizations. Experiment 3 was designed to test whether the fake hand effect was any stronger when observers could feel the rubber material on their own hands compared to when their hands were bare.

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5 This estimation came from dividing the largest CE in the Fake Hand condition (128 ms) from that in the Real Hand Baseline (189 ms), and multiplying by 100.
Experiment 3

The main question addressed in the present experiment was whether a tactile sensory experience, in addition to a visual one, could influence the magnitude of the fake hand effect. That is, can the experience of feeling soft plastic on one's hands at the same time as seeing the soft plastic of the fake hands enhance the fake hand effect. To test this, observers wore a pair of soft plastic kitchen gloves on their hands that matched those used to construct the fake hands. The prediction was that if the feel of plastic on one's hands increases tactile mislocalizations, then CEs would be larger when observers wore a pair of soft plastic gloves compared to when their hands remained bare.

Methods

Participants: Fourteen undergraduate students at the University of British Columbia participated in the 45-minute experimental session in return for partial course credit. All observers reported normal or corrected-to-normal vision. Further descriptive information on observers is provided in Table 1. Observers were naïve to the purpose of the experiment and were fully debriefed upon completion.

Apparatus: Similar to that used in Experiment 2. Observers laid their arms on the surface of a table (within arm boundaries on either side), and underneath a smaller stand. They held a foam cube in each hand. Each foam cube contained a pair of tactile vibrators as described in Experiment 1. A black cloth was draped over the surface of the smaller stand obstructing a view of the observer’s hands. An additional foam cube was aligned above each of the observer’s hands below. This pair of cubes held pairs of distractor LEDs. Again,
these were as described in Experiment 1. On half of the trials, observers were required to wear a pair of pink soft plastic kitchen gloves (a variety of sizes were available). As well, observers wore a pair of thin disposable glove liners inside the kitchen gloves for sanitary purposes.

**Stimuli:** Same as that used in Experiment 2. The target was one of four possible tactile vibrators, and the distractor one of four possible LEDs.

**Design:** Observers participated in three training sessions of 15 trials each, followed by eight experimental blocks of 96 trials. In addition to the within-observer factors of Condition (No Fake Hand, Fake Hand), Congruency (Congruent, Incongruent), and Distractor Side (Same, Opposite), there was an additional within-observer factor referred to as Observer Gloves (None, Plastic).

**Procedure:** Same as that in Experiment 2.

**Results**

RT CEs and Error CEs were the main measures of interest. They were calculated in the same way as before (Incongruent RT minus Congruent RT). The analyses consisted mainly of repeated measures ANOVAs. Significant two-way interactions of interest were followed up by simple effects testing while significant main effects of interest were followed up using Least Significant Difference testing.

The main finding of interest in the present study was that CEs were the same magnitude in the Fake Hand condition whether observers experienced the feel of soft plastic on their hands or their hands remained bare, see Figure 7. Additionally, as expected, a target-distractor separation effect was obtained where CEs were consistently larger when the target and distractor were
presented on the same side of fixation (see Figure 7A) than when they were presented to opposite sides (see Figure 7B).

A Same

B Opposite

Figure 7. Mean CE (in ms) for Experiment 3 as a function of Condition (No Fake Hands, Fake Hands), Observer Gloves (Plastic, None) for (A) Same and (B) Opposite side target-distractor presentations.

A 3-factor repeated measures ANOVA was computed using Condition (No Fake Hand, Fake Hand), Distractor Side (Same, Opposite) and Observer Gloves (None, Plastic) as factors, and RT CEs as the dependent variable. See Figure 7. Only the main effects of Condition [F (1, 13) = 10.77, p < .01, MSE = .3143] and Distractor Side [F (1, 13) = 16.93, p < .01, MSE = 3692] were significant. All remaining p's > .10. These results indicate that CEs were larger overall in the Fake Hand condition (94 ms) versus the No Fake Hand condition (59 ms). As expected, CEs were larger overall when the target and distractor were presented on the same side of fixation (100 ms) versus the opposite side (53 ms). None of the main effects or interactions involving the Observer Gloves factor reached significance. This indicates that CE magnitudes were the same regardless of whether observers felt plastic on their hands or not.
The same analysis as that above was repeated using Error CEs as the dependent variable. Only the main effect of Distractor Side \( [F (1, 13) = 11.73, p < .01, \text{MSE} = 33] \) and the three-way interaction of Condition x Distractor Side x Observer Gloves \( [F (1, 13) = 8.82, p < .05, \text{MSE} = 8.5] \) were significant. The three-way interaction was examined by looking at the simple Condition x Distractor Side interaction separately for Gloves and No Gloves. When the data was restricted to the trials where observers wore gloves, the simple Condition x Distractor side interaction did not reach significance, \( F < 1 \). When the data was restricted to trials where observers did not wear gloves, the simple interaction was significant, \( F (1, 13) = 8.26, p < .05, \text{MSE} = 18 \). To understand it better, it was broken down by looking at the simple effect of Condition for same and opposite side target-distractor presentations. When targets and distractors were presented on the same side, Error CEs were larger overall in the Fake Hand condition (12%) than in the No Fake Hand condition (4%), \( F (1, 13) = 4.82, p < .05, \text{MSE} = 97 \). When targets and distractors were presented on the opposite side, the simple main effect of Condition did not reach significance, \( F < 1 \). Since the Error CEs were either not significant, or their pattern was consistent with the pattern of the RT CEs, speed accuracy tradeoffs were not a concern.

**Discussion**

The results of Experiment 3 suggest that the feel of soft plastic does not enhance the fake hand effect. That is, the magnitude of the CEs remained the same whether or not observers felt soft plastic on their hands. This suggests that the fake hand effect is not driven by the tactile experience of wearing gloves that match the visual information about the gloves. Nor is it necessary to have a perfect match in either the texture or visual material of the fake and the real...
hands. Did wearing gloves have the effect of weakening the tactile signal overall? This possibility is eliminated by the observation that the speed and accuracy of detection of the target tactile vibrations were not affected by whether observers wore gloves or not, which suggests that the tactile signal was unchanged by the gloves.

If not driven by the 'feel' of a glove, what factors then underlie the tendency to mislocalize tactile targets to the fake hand? It is clear from the previous experiments that there is a visual component to the effect, but it remains uncertain as to what specific visual aspects matter for generating it. Pavani et al. (2000) suggest that the mislocalization effect “is specific to the case in which the rubber hand is aligned so as to look plausibly like the participant’s own hand” (p. 356). Recall that their alignment manipulation involved either keeping the fake hand aligned with the observer’s hand below, or turning the fake hands outward so that they were misaligned with the observer’s hands but still continued to ‘hold’ the distractor lights. Note that this manipulation also involved a change in posture. That is, when the fake hands were aligned with the observer’s hands, the postures of the real and fake hands matched, but when they were misaligned, the postures mismatched. The question that remains from this is whether observers will continue to mislocalize tactile targets to the fake hand if the alignment between the real and fake hands is maintained, but the postures mismatch (e.g., fake hands in a prone posture, real hands in a supine posture).

Analyses using correct RTs and Errors as dependent variables revealed that the Observer Gloves main effect was not significant in either analysis, nor did this factor interact with any of the other factors, p’s > .05.
Experiment 4

Pavani et al. (2000) reported that the fake hand effect disappears when the fake hands are misaligned with the observer's hands. The authors asserted that the alignment of the hands was necessary for the fake hand effect. There are, however, at least two other possible explanations for the pattern of results that they obtained. One, by misaligning the fake hands with the observer's hands, the authors also had the effect of changing the posture of the former with respect to the latter. It could be that in doing so, the fake hand's posture was seen as implausible (i.e., would elicit a different set of proprioceptive signals than the observer's hand was suggesting), and as a result, the fake hand could no longer be misperceived as belonging to the observer. Two, the authors' repositioning of the fake hands when they were misaligned meant that there was no longer a direct visual path to the distractor lights. If the role of the fake hand is to direct the observer's attention to the distractor lights by creating a straight line of sight, this role would be compromised by the misalignment of the fake hands.

In order to test the contributions of postural matches in the fake and real hands to the fake hand effect, Experiment 4 was designed such that the alignment of the hands was held constant (the hands were always pointing in the direction of the distractor lights) and only the postures were changed. In this design, the postures of the fake hands and real hands either matched (both prone or both supine), or mismatched (one prone the other supine). If a match in posture is an important factor in generating the larger CEs in the Fake Hand versus No Fake Hand condition then one would expect this pattern only when the postures of the real and fake hands match but not when they mismatch,
despite that the hands are aligned in both cases. If posture turns out to be a relevant factor to the fake hand effect, this would support the idea that it is the personal limb identification that the observer has with the fake hands that is relevant rather than the subsidiary effect of aligning the observer's gaze with the distractor lights. Note that if the latter is the important factor, the fake hand effect should persist whether the postures match or mismatch since the fake hands are pointed in the direction of the distractor lights in both cases.

Methods

Participants: All 28 participants were volunteer Psychology undergraduate students from the University of British Columbia. They received partial course credit for their participation in the 45-minute experimental session. Descriptive information can be found in Table 1.

Apparatus: Similar to Experiment 3.

Stimuli: Same as Experiment 3

Details: Observers participated in three practice blocks of 15 trials (as described earlier). There were six experimental blocks of 96 trials. Observers were randomly assigned to one of two Observer Hand Orientations: prone or supine. In the prone position, observers rested their finger on the top tactile vibrator and thumb on the bottom tactile vibrator, as before. In the supine position, observers adopted the reverse position (i.e., rested their finger on the bottom tactile vibrator and thumb on the top tactile vibrator). All remaining factors were within-observer and included: Fake Hand Condition (No Fake Hand, Prone, Supine), Distractor Side (Same, Opposite). Note that for a prone fake hand, the finger of the fake hand rested next to the upper distractor light, and the thumb next to the lower distractor light, as before. For a supine fake
hand, the finger was next to the lower distractor light, and the thumb next to the upper distractor light.

Every observer participated in 576 trials (6 blocks * 96 trials per block). On 192 of those trials the orientation of the fake hands was consistent with that of the observer's hands (e.g., observer's hands prone, fake hands prone). On another 192 trials, the orientation of the fake hands was inconsistent with that of the observer's hands (e.g., observer's hands prone, fake hands supine). On the remaining 192 trials, the fake hands were absent. At the end of each experimental block, the experimenter had to alter the setup slightly (e.g., remove the fake hands, change the orientation of the hands).

Procedure: Similar to Experiment 3 with one exception. Observers in the Prone condition were instructed to respond using a toe lift when they localized the tactile vibration to their finger (top digit), and to respond with a heel lift when they localized the tactile vibration to their thumb (bottom digit). This was as before. In contrast, observers in the Supine condition were given the reverse instructions; to respond with a toe lift when the tactile vibration was localized to their thumb (top digit), and respond with a heel lift when the tactile vibration was localized to their finger (bottom digit). By giving these instructions to observers in the supine condition, the stimulus-response mapping was held constant across limb orientations such that a tactile vibration on the top digit was always paired with a toe lift response, and a tactile vibration on the bottom digit was always paired with a heel lift response.

Results

The measures of interest were again the RT CEs and Error CEs. Mixed design ANOVAs were computed using Observer Hand Orientation (Prone,
Supine) as a between-observer factor and Fake Hand Condition (No Fake Hand, Prone, Supine), and Distractor Side (Same, Opposite) as within-observer factors. Significant interactions and main effects were followed up using simple effects testing, and least significant difference testing.

The main finding of the present study was that tactile mislocalizations were present only when the orientation of the fake hands was consistent with that of the observer’s hands, see Figure 8. When the two were inconsistent, CEs resembled those obtained when there were no fake hands, suggesting that tactile mislocalizations are less common when the fake hand’s orientation is implausible with respect to the observer’s hand. Additionally, when the observer’s hands are supine, the fake hand effect is weaker overall than when the observer’s hands are prone (i.e., CEs in the Consistent condition for supine observer hands are in the direction of being larger than those in the No Fake Hand condition, but the two are statistically similar).

![Graphs showing mean CE (in ms) for Experiment 4 as a function of Fake Hand Condition (No Fake Hand, Inconsistent, Consistent) and Observer Hand Orientation (Prone, Supine) for (A) Same and (B) Opposite target-distractor presentations.]

Figure 8. Mean CE (in ms) for Experiment 4 as a function of Fake Hand Condition (No Fake Hand, Inconsistent, Consistent) and Observer Hand Orientation (Prone, Supine) for (A) Same and (B) Opposite target-distractor presentations.
When RT CEs were the dependent variable, the main effect of Distractor Side was significant, and indicated that CEs were larger overall for same side target-distractor presentations than for opposite side presentations (97 ms vs. 53 ms), $F(1, 26) = 25.16, p < .01, \text{MSE} = 812$. The Fake Hand Condition x Observer Hand Orientation interaction was also significant, $F(2, 52) = 6.83, p < .01, \text{MSE} = 2077$. To better interpret this interaction, the simple effect of Fake Hand Condition was examined separately for Prone and Supine observer hand orientations. When the observer’s hands were in a prone orientation, the main effect of Fake Hand Condition was significant, $F(2, 26) = 5.14, p < .05, \text{MSE} = 1280$. Least significant difference testing revealed that CEs were largest when the fake hands were prone (94 ms), rather than supine (72 ms) or absent (64 ms), $p's < .05$. The CEs did not differ in the latter two cases, $p > .20$. When the observer’s hands were in a supine orientation, the main effect of Fake Hand Condition was again significant, $F(2, 26) = 3.80, p < .05, \text{MSE} = 2874$. CEs were largest overall when the fake hands were supine (95 ms) compared to prone (55 ms), $p < .05$. Neither paired comparison involving the No Fake Hand condition (72 ms) reached significance, $p's > .10$.

The same analysis as that above was computed using Error CEs as the dependent variable. The main effect of Distractor Side was significant, $F(1, 26) = 22.68, p < .01, \text{MSE} = 3$. Overall, CEs were larger for same side (6.8%) versus opposite side (3.0%) target distractor presentations. Since the error CEs were either not significant, or their pattern is similar to that found for RT CEs, this eliminates concern for speed accuracy tradeoffs.
Discussion

The most important observation from the above analysis was that the fake hand effect was most compelling when the orientation of the fake hands was consistent with that of the observer's hands. In fact, when the orientations were inconsistent, the pattern of CEs resembled those found in the No Fake Hands condition. These results suggest that the fake hand effect occurs when observers can incorporate the fake hands into their body schema (i.e., treat them as their own). It does not appear to be the case that the role of the fake hands is simply to direct the observer's attention to the distractor lights, which would happen whether the orientation of the fake hands were consistent or inconsistent with the orientation of the observer's hands.

The present results are consistent with the results of a study reported by Maravita, Spence, Kennett and Driver (2002) wherein observers incorporated a tool held in their hands into their body schema. In a setup similar to the one used presently, observers held a pair of plastic golf clubs in their hands, and the pair of tactile vibrators was positioned on the handle of the tool so that there was a tactile vibrator on the observer's finger and thumb. Observers were to report the location of the target tactile vibration. A pair of distractor lights positioned 75 cm away from observer's hands, were 'connected' to the tactile vibrations by the tools. The authors reported the typical pattern of CEs such that CEs were larger for same side versus opposite side target-distractor pairs. As demonstrated in the present Experiment 1, the CE is influenced by target-distractor separation. Given the distance between targets and distractors used by Maravita et al., the tools must have successfully bridged that distance, just as the
fake hands in the present study have. These findings suggest that the tools were incorporated into the observer's body schema.

Response mappings were assigned in Experiment 4 such that a tactile vibration delivered to the top digit was always paired with a toe lift response (top-toe), and a tactile vibration delivered to the bottom digit was paired with a heel lift response (bottom-heel). Are these response mappings relevant to the fake hand effect? Will the fake hand effect persist if these response mappings are reversed such that a tactile vibration delivered to the top digit is paired with a heel lift response (top-heel), and a tactile vibration delivered to the bottom digit is paired with a toe lift response (bottom-toe)? Experiment 5 was designed to address this question.

**Experiment 5**

There is a large literature dating from the 1950's that deals with the influence of stimulus-response compatibilities on response times (e.g., Fitts & Seeger, 1953, see Alluisi & Warm, 1990). Typically, in these experiments, observers are asked to make a forced choice key press, a manual pointing response, a joystick movement, or a verbal response to a visual stimulus. Consistently within that literature, response times are fastest when there is a direct spatial translation between the stimulus and response (e.g., responses to a left visual stimulus are faster when observers are asked to make a left versus right keypress). Additionally, observers are faster to respond when the response type is consistent with the stimulus type (e.g., manual response for a spatial stimulus or a vocal response for a verbal stimulus; Proctor and Wang, 1997). In
contrast, RTs are slowed when the spatial translation between stimulus and response is indirect or when the stimulus and response types differ.

Chua and Weeks (1997) proposed a way in which to conceptualize the factors involved in stimulus-response compatibility effects. **Mapping** refers to the assignment of a specific response to a given stimulus (e.g., left keypress for left stimulus, right keypress for right stimulus). **Configuration relation** refers to the layout of the stimulus display relative to the response array (e.g., parallel versus orthogonal stimulus display and response array). **Global relation** refers to the relative spatial location of the stimulus display and response array (e.g., stimulus display at the midline, response array aligned with the shoulder on the right). Included within this latter division is the orientation of the observer with respect to either the stimulus display or response array (Chua et al., 2001). All three factors contribute to a different extent to the stimulus-response compatibility effects.

When the configuration relation is orthogonal, such that the stimulus display is vertical and the response array is horizontal, preferences for particular mappings seem to arise, such that a top-stimulus paired with a right-response and a bottom-stimulus paired with a left-response is faster than the opposite pairings (e.g., Michaels, 1989). These preferences tend to depend on the global relations (i.e., reverses when the response is made in the left hemispace; Weeks, Proctor & Beyak, 1995).

When Experiment 4 is considered within the framework of Chua and Weeks (1997), the manipulations of interest were mainly at the mapping level and to a minimal extent at the global relation level (orientation of observer’s arm), whereas the configuration relation remained constant (vertical stimulus display).
display paired with a front-back response array). It is possible that in Experiments 1-4, the response mappings assigned to observers took advantage of the most direct translation between the vertical stimulus array and the front-back response array. That is, it may be that the translation between the top digit to the toe lift (front pedal) and between the bottom digit to the heel lift (back pedal) were the most direct stimulus-response translations for those particular arrays. If so, this raises the possibility that the reverse response mapping assignments, wherein a tactile vibration delivered to the top digit is mapped to a heel lift response, and a tactile vibration delivered to the bottom digit is mapped to a toe lift response, might disrupt the fake hand effect.

Experiment 5 was designed to examine the possible role of response mapping in the fake hand effect. Two conditions were included wherein observers were asked to respond to a tactile vibration on the top digit using a heel lift (back pedal), and to a tactile vibration on the bottom digit using a toe lift (front pedal). These response mappings were the reverse of those assigned in Experiment 4. The data from the two conditions in Experiment 5 were combined with those from Experiment 4 so that it was possible to look at all combinations of Digit-Response Mapping (top-toe & bottom-heel versus top-heel & bottom-toe) and the two levels of Observer Hand Orientation (Prone, Supine) to see whether the CEs were the same under all combinations. The same three fake hand conditions as those tested in Experiment 4 were again introduced: No Fake Hands (1/3 of trials), Consistent Fake Hands (1/3 of trials), and Inconsistent Fake Hands (1/3 of trials).
Methods

Participants: Twenty-eight volunteers from the undergraduate Psychology program at the University of British Columbia participated in the 45-minute experimental session for partial course credit. Descriptive information can be found in Table 1.

The remainder of the method was identical to Experiment 4 with the exception that the response mappings were reversed. This meant that a tactile vibration delivered to the top digit was always paired with a heel lift response, and a tactile vibration delivered to the bottom digit was always paired with a toe lift response. Thus, for observers in the Prone condition, the finger (top digit) was mapped to the heel, and the thumb (bottom digit) was mapped to the toe, while for the observers in the Supine condition the thumb (top digit) was mapped to the heel, and the finger (bottom digit) was mapped to the toe.

Results

Because the focus of the present study was on the interaction between response mapping and observer hand orientation, the present data were combined with that of the previous experiment so that it was a complete 2 x 2 design with two levels of Digit-Response Mapping (top–toe & bottom–heel versus top–heel & bottom–toe) combined with two levels of Observer Hand Orientation (Prone, Supine). CEs were calculated in the same way as in previous experiments where Correct RTs or Errors on Congruent trials were subtracted from Correct RTs or Errors on Incongruent trials. Note that congruent and incongruent still refer to the elevation of the distractor light with respect to the target tactile vibration.
The dependent measures of interest were the RT CEs and Error CEs. Mixed design ANOVAs were computed using Fake Hand Condition (No Fake Hand, Consistent, Inconsistent), and Distractor Side (Same, Opposite) as within-observer factors, and Digit-Response Mapping (top-toe & bottom-heel versus top-heel & bottom-toe) and Observer Hand Orientation (Prone, Supine) as between-observer factors. Significant interactions and effects were followed up using simple effects testing, and least significant difference testing.

There are three main findings. First, overall CEs were larger when the fake hands were present and in a posture consistent with that of the observer's hands. This is as expected based on the results of the previous experiment.

Second, the effect is weaker overall when observers adopt a top-heel & bottom-toe mapping (see Figure 9) versus a top-toe & bottom-heel mapping (see Figure 8). That is, for the former mapping assignment, CEs in the Consistent Fake Hand condition are no longer significantly larger than those in the remaining two conditions.

Three, the fake hand effect pattern was altered in the case where the observers' hands were in a supine position, and a top-heel & bottom-toe mapping was assigned (in this case, a tactile vibration localized to the thumb required a heel lift response and a tactile vibration localized to the finger required a toe lift response). Under these conditions, the CEs were typically negative, and their absolute values smaller than the CEs for the other combinations (see the rightmost bars of Figure 9A). Note that a negative CE in this case reflects the fact that observers are faster on incongruent versus congruent trials. In other words, under these conditions, observers are faster to respond, for example, to a tactile vibration on the thumb (top digit) when it is
paired with a bottom distractor light (incongruent), and slower when paired with a top distractor light (congruent). Interestingly, there was a trend, though it was not significant, for CEs to increase (in the negative direction) when the fake hand was present and its postural rotation was inconsistent with that of the observer's hand (i.e., the fake hand was prone, the observer's hand was supine).

A 2 within (Fake Hand Condition and Distractor Side) and 2 between (Digit-Response Mapping and Observer Hand Orientation) mixed design ANOVA was computed. All of the main effects were significant, p's < .05: Digit-Response Mapping [F (1, 52) = 18.22, p < .01, MSE = 13347], Observer Hand Orientation [F (1, 52) = 9.13, p < .01, MSE = 13347], Condition [F (2.104) = 4.52, p < .05, MSE = 3257], and Distractor Side [F (1, 52) = 14.09, MSE = 13347], see Figures 8 and 9. The main effect of Fake Hand Condition indicated that CEs were larger overall in the Consistent condition (61 ms) than either the No Fake Hand (45 ms) or Inconsistent condition (39 ms), p's < .05. The comparison between the latter two conditions did not reach significance, p > .20. The other main effects were tempered by significant interactions of Response Mapping x Observer Hand Orientation [F (1, 52) = 7.89, p < .01, MSE = 13347], Distractor Side x Response Mapping [F (1, 52) = 4.68, p < .05, MSE = 4607], Distractor Side x Observer Hand Orientation [F (1, 52) = 10.91, p < .01, MSE = 4607], and Distractor Side x Response Mapping x Observer Hand Orientation [F (1, 52) = 7.34, p < .01, MSE = 4607].
The 3-way interaction above was followed up by looking at the simple interaction of Digit-Response Mapping x Observer Hand Orientation for same and opposite side target-distractor presentations. When targets and distractors were presented to the same side of fixation, the Response Mapping x Observer Hand Orientation interaction was significant, $F(1, 52) = 10.38, p < .01$, $MSE = 12450$. This was further broken down by looking at the simple effect of Response Mapping for prone and supine hand positions. When the observer’s hands were prone, the main effect of Response Mapping was not significant, $F < 1$. When the observer’s hands were supine, CEs were larger overall when a top-toe and bottom-heel mapping was assigned (94 ms) versus a top-heel and bottom-toe mapping (-32 ms), $F(1, 26) = 45.85, p < .01$, $MSE = 7192$. When targets and distractors were presented to the opposite side of fixation, the simple interaction of Digit-Response Mapping x Observer Hand Orientation was not significant, $F(1, 52) = 1.80, p > .10$, $MSE = 5504$. 

Figure 9. Mean CE (in ms) for a top-heel & bottom-toe digit-response mapping as a function of Fake Hand Condition (No Fake Hand, Inconsistent, Consistent) and Observer Hand Orientation (Prone, Supine) for (A) Same and (B) Opposite target-distractor presentations.
After examining the data in Figures 8 and 9, it seemed appropriate to do four additional, but more specific comparisons to test whether the fake hand effect varied across the four combinations of Digit-Response Mapping and Observer Hand Orientation. When the observer's hand was prone and a top-toe & bottom-heel mapping was assigned (see Figure 8), the main effect of Condition was significant, $F(2, 26) = 5.14, p < .05, \text{MSE} = 1280$. CEs were larger for the Consistent Fake Hand condition (94 ms) than either the No Fake Hand (64 ms) or Inconsistent conditions (72 ms), $p's < .05$. When the observer's hand was prone but a top-heel & bottom-toe mapping was assigned (see Figure 9), the main effect of Condition was no longer significant, $F(2, 26) < 1, \text{MSE} = 5390$. CEs were the same magnitude for the No Fake Hand (59 ms), Consistent Fake Hand (53 ms), and Inconsistent Fake Hand conditions (62 ms). When the observer's hand was supine and a top-toe & bottom-heel mapping was assigned (see Figure 8), the main effect of Condition was again significant, $F(2, 26) = 3.80, p < .05, \text{MSE} = 2875$. The CEs in the Consistent condition (95 ms) were larger than those in the Inconsistent condition (55 ms), $p < .05$. No comparisons with the No Fake Hand condition (70 ms) reached significance, $p's > .10$. Finally, when the observer's hand was supine and a top-heel & bottom-toe mapping was assigned (see Figure 9), the main effect of Condition only approached significance, $F(2, 26) = 2.60, p < .10, \text{MSE} = 3484$. CEs were larger in the Inconsistent (-33 ms) versus the Consistent (3 ms) conditions, $p < .05$. No comparisons with the No Fake Hand condition reached significance, $p's > .20$.

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7 These comparisons were computed even though the Condition x Digit-Response Mapping x Observer Hand Orientation interaction was not significant.
The overall analysis above was computed using Error CEs as the dependent variable. Only the main effects of Response Mapping \([F (1, 52) = 15.89, p < .01, \text{MSE} = 62]\) and Distractor Side \([F (1, 52) = 19.30, p < .01, \text{MSE} = 31]\) were significant. These main effects were tempered by significant interactions of Digit-Response Mapping \(\times\) Observer Hand Orientation \([F (1, 52) = 4.50, p < .05, \text{MSE} = 62]\), and Distractor Side \(\times\) Digit-Response Mapping \([F (1, 52) = 5.23, p < .05, \text{MSE} = 31]\). These interactions were followed up by first looking at the simple main effect of Digit-Response Mapping for prone and supine observer hands. When the observer’s hands were prone, the simple main effect was not significant, \(F (1, 26) = 1.75, p > .20, \text{MSE} = 61\). When the observer’s hands were supine, CEs were larger overall for the top-toe and bottom-heel mapping (5%) versus the top-heel and bottom-toe mapping (0%), \(F (1, 26) = 18.55, p < .01, \text{MSE} = 62\).

The Distractor Side \(\times\) Digit-Response Mapping interaction was followed up by looking at the simple main effect of Digit-Response Mapping for same and opposite side target-distractor presentations. When targets and distractors were presented to the same side of fixation, CEs were larger when the mapping assignment was top-toe and bottom-heel (7%) versus top-heel and bottom-toe (2%), \(F (1, 52) = 16.27, p < .01, \text{MSE} = 65\). When targets and distractors were presented to the opposite side of fixation, CEs were larger for a top-toe and bottom-heel mapping assignment (3%) versus top-heel and bottom-toe mapping assignment (1%), \(F (1, 52) = 8.68, p < .01, \text{MSE} = 27\).

**Discussion**

There were two main findings in this Experiment.
Digit-Response Mapping and Observer Hand Orientation influence the effect:

The definitive pattern for the fake hand effect of larger CEs in the Consistent Fake Hand condition than the remaining two conditions is less pronounced when the observer adopts a top-heel & bottom-toe mapping. This is especially true in the case where the observer’s hand is supine. This suggests that the fake hand effect is sensitive to response mapping, and to posture when response mapping is manipulated. Note that when a top-toe & bottom-heel mapping was adopted, the effect persisted for either hand orientation. This suggests that the observer’s hand orientation by itself does not influence the effect, but rather what matters are the digit-response mappings and the visible fake hand orientations that it is paired with.

Negative CEs for Supine Hands and Top-Heel & Bottom-Toe Mapping:

The negative CEs indicate that observers are faster to localize the tactile target when the elevation of the distractor light is incongruent rather than congruent with the elevation of the tactile target. This reverse CE pattern is only observed for this particular combination of observer hand orientation and digit-response mapping. Additionally, when the orientation of the fake hand is prone, and thus the visual information is inconsistent with the supine orientation of the observer’s hand, the reversed CE pattern tends to be more pronounced, although not significantly so. This latter result suggests that in this particular condition observers may have mentally rotated their hand to the prone orientation, as consistent with the available visual information.
General Discussion

Touch is a proximal sense in that tactile sensations typically arise through direct skin contact (Cholewiak & Collins, 1991). The tactile receptors under the skin are plentiful enough that relatively accurate body-relevant localizations are possible. This makes it fairly easy to tell that something is touching your finger instead of your thumb. But, it is a rather different matter to be able to judge the precise location of this touch in the three dimensional space that surrounds you. The touch to your finger will feel the same, for example, whether your finger is in front of your body, or behind your back. To know where the touch occurred in the surrounding space, the body-relevant tactile information must be combined with other sensory information such as is given through proprioception and vision (e.g., Botvinick & Cohen, 1998; Pavani et al., 2000).

The first question of the present study was “Can tactile targets be mislocalized to a new spatial location that is initially specified solely by vision?” The subjective impressions collected from observers in the Pavani et al. (2000) study suggested that the tactile vibrations were mislocalized to the digits of a fake hand. The authors, however, did not include an appropriate baseline measure with which to objectively confirm the perceived locations of the tactile vibrations. Did observers behave as though the tactile vibrations were presented at the location specified by vision of the fake hands?

The initial step in addressing this question was to introduce a new baseline condition wherein the observer’s hands were positioned in the location normally occupied by the fake hands (Experiment 1). By doing so, it was possible to measure tactile localization responses when the true location of the
tactile vibrations was the same as the subjective location of the tactile vibrations normally induced by the presence of the fake hands. This key baseline condition revealed that, in contrast to the qualitative and subjective reports of observers, the quantitative measurement of the fake hand effect indicated that the experience was not identical to that of having one’s own hand in the same location as the fake hand. Rather, the fake hand effect resulted in a weaker measure of perceptual congruency than when the observer’s hands occupied that same location.

Despite these quantitative differences, however, there were qualitative similarities in response patterns across these two conditions in the way that observers responded to manipulations of target-distractor spatial separation. This latter result is consistent with observer’s subjective impressions indicating that they identified with the limb to some extent.

In order to determine whether the fake hand effect depended on observers seeing the fake hand, or whether it was sufficient to have partial visual information consistent with its presence, the fake hand was hidden under a cloth cover (Experiment 1) or under a box cover that eliminated visual information about its shape (Experiment 2). The fake hand effect persisted in both cases. This is the first piece of evidence that the effect is not driven purely by direct vision, but rather, may arise from existing knowledge that is reinforced through partial vision. The results of Experiment 2, however, also indicated that when there was both a hidden fake hand and a visible fake hand, the effect was smaller on the side of the hidden hand. This suggests that observers can reassign weights to different sources of information depending on what is available so that they can make the best estimate about the location of a tactile stimulus. That
is, in the case where there is direct visual information in one location, and indirect visual information in another, the former is weighted more heavily than the latter.

Experiment 3 was designed to address the question of whether the fake hand effect could be enhanced by the availability of additional tactile information that was congruent with the fake hands – the feel of soft plastic on one’s hands. The results revealed that the magnitude of the effect was the same whether observers wore gloves or not. This suggests both that the fake hand effect does not depend on a perfect visual or tactual match between the fake hand and the observer’s hand, and that continuous tactile reinforcement, as that gained from wearing the soft plastic gloves, does not contribute to the effect.

In Experiment 4, the rotational posture of the fake hands was manipulated such that their posture was either consistent or inconsistent with that of the observer’s hands. The fake hand effect was present only in the former case. That is, the effect disappeared when the rotational posture of the fake hands was inconsistent with that of the observer’s hands. This was true despite the fact that the fake hands were always aligned with the observer’s hands below and were positioned to ‘hold’ the distractor lights. These results suggest both that the fake hand must be a plausible extension of the observer’s body, and that the effect is not simply a product of the fake hands creating a direct line of sight to the distractor lights, because they do so for either rotational posture.

The digit-response mapping assigned throughout Experiments 1-4 was the same – respond to a tactile vibration on the top digit using the toe lift response and a tactile vibration on the bottom digit using the heel lift response (top-toe & bottom-heel). Using the basic experimental design of Experiment 4,
the digit-response mapping assignment was reversed in Experiment 5 - respond to a tactile vibration on the top digit using the heel lift and a tactile vibration on the bottom digit using the toe lift (top-heel & bottom-toe). By combining the data from Experiments 4 and 5, it was possible to look at the magnitude of the fake hand effect for different combinations of observer hand orientation (prone, supine) and digit-response mapping (top-toe & bottom-heel versus top-heel & bottom-toe).

Interestingly, the fake hand effect was weaker for the top-heel & bottom-toe mapping than for the reverse mapping. Furthermore, when the observer's hands were in a supine orientation and a top-heel & bottom-toe mapping was assigned, the effect was not only weaker overall, but the CEs were in the negative direction. This result suggests that the fake hand effect is not only sensitive to the rotational posture of the fake hand (Experiment 4), but it is also sensitive to posture when particular response mappings are adopted such that when the hand is supine, the finger or bottom digit does not map well onto the toe and the thumb or top digit does not map well onto the heel. It is worthwhile to highlight that a negative CE indicates that observers were faster to respond to the location of the tactile vibration when the location of the distractor light was incongruent rather than congruent. These negative CE are unique to this particular combination, and tend to increase when the fake hands are in a prone orientation (i.e., inconsistent). One way to reconcile this pattern of results with the others is by imagining that observers responded by first mentally rotating their hand into a prone or default position before responding. This would have the effect of making the negative CEs positive, and a prone fake hand consistent with the
imagined posture of the observer's hand. More research is needed to explore this possibility.

**Implications of the Present Results**

The present results have a number of implications for understanding how body schemas are formed. In turn, these principles can be used to improve such things as the construction and fitting of limb prostheses, and remote surgery.

**Formation of Body Schemas:**

As noted throughout the present study, tactile localization in three-dimensional space is influenced by vision, even when the available visual and proprioceptive information conflict. Knowing that the tactile stimuli are delivered to the digits of their own hand, but mislocalizing them towards the fake hand implies that perceived limb position is also vulnerable to vision, and that observers must somehow incorporate the fake hand within their body schema (e.g., adopt the fake hand as an extension of the body). This is consistent with the subjective reports collected from previous studies (e.g., Botvinick & Cohen, 1998; Pavani et al., 2000).

Since the fake hand effect was sensitive to a variety of manipulations, this suggests that the human body schema is flexible under some conditions but is inflexible under others. The finding of a fake hand effect under both full and partial vision conditions, for instance, indicates that body schemas may be modified by indirect visual cues. In contrast, the absence of the fake hand effect when the rotational posture of the fake hand was inconsistent with that of the observer's hand suggests that changes to the observer's body schema likely require that the fake hand be seen as a plausible extension of the observer's body.
This latter notion is consistent with the earlier findings of Pavani et al. (2000) that to obtain the fake hand effect the fake hands had to be aligned with the observer’s body in a plausible way. More research is needed to determine what is flexible about body schema and what is not.

**Acceptance of Prosthetic Limbs:**

Further research on what factors make the fake hands plausible extensions of an observer’s body can be applied to the use of prosthetic limbs such that they are constructed so as to be a more accepted and natural part of the user’s body. The present results suggest, for example, that the texture or feel of a prosthetic limb may not be as important a factor as the consistency between the seen posture of the limb and the expected posture.

Ramachandran and Hirstein (1998) tested patients who were missing a limb and who reported experiencing a ‘phantom’ in its place (i.e., a nonvisible limb). The authors used a mirror to give the phantom limb patients the impression that they could see their phantom (actually just a reflection of the normal hand) in which case, patients reported experiencing a touch on the phantom limb when tactile stimuli were delivered to the normal hand. One way to think about these results is that the authors provided phantom limb patients with visual feedback of the limb that was sufficient for patients to accept that the limb was present. This mirror technique would not likely have been effective if the patients believed that the posture of the phantom was different from the seen posture. The results of the present study suggest that another way to provide feedback about the limb is to alter one’s metacognitions about where their limb is in space, what posture it is in, and that it is functioning. This could perhaps be done by first having the patients participate in an imagery session, where they
try to picture their limb in an assigned orientation. Once patients report having done this successfully, the imagery tasks could then be expanded to include imagining different movements like the opening and closing of the palm prior to employing the mirror technique.

**Human-Machine Interactions:**

Another possible application of the present results to the real world is in the domain of design issues with respect to remote surgery. Remote surgery is the process by which a surgeon, for example, manipulates tools held by a robotic arm through joystick manipulation from one location, while the patient being operated on and the robotic arm manipulated are in a separate location. To do this requires that the surgeon receives visual feedback of the remote site in a location that is removed from the actual site (e.g., doctor in Vancouver performing an operation on a patient in Burnaby, with surgical feedback provided on a video monitor). Visual feedback in this case is thus separated from the proprioceptive feedback, in much the same way that the visible fake hands in the present study were spatially separated from the location of the observer's hands. Research indicates that the location of this visual feedback is likely an important factor in performance (Hanna, Shimi, & Cuschieri, 1998; MacKenzie, Graham, Cao, & Lomax, 1999; Mandryk & MacKenzie, 2000).

Results reported by Mandryk and MacKenzie (2000), for instance, suggest that there may be an advantage to superimposing the image from the video monitor above where the controls are manipulated rather than at a 90° angle, as is typical when looking up at a monitor.

The present results suggest that the tactual congruence between the robotic arms and the surgeon's arms may not be an issue, but that matching the
posture of the robotic arms with respect to the surgeon’s arms may be a critical factor for successful use of the tools. It may be problematic, for example, to have the robotic arms operating in a supine posture while the surgeon’s arms are prone. Additionally, the present results suggest that the combination of the posture of the arms and the mapping between the available visual information (stimulus) and the required action (response) may also influence the efficiency and accuracy of the surgeon’s responses. Further research is needed, however, to determine whether rotational inconsistencies between the fake hands and the observer’s hands are as important when they are explicable by something such as camera angle. If there is a reasonable explanation for these differences (e.g., mirror reversal, or projected on a monitor so dependent on camera angle), then it may be the case that the fake hand effect will persist even when the rotational postures are inconsistent.

**Outstanding Questions and Future Directions**

**Is the Fake Hand Effect Generalizable to Non-Hand Objects?**

Measures were taken in the present study to construct the fake hand so that it was undeniably hand-like. The soft plastic glove, for instance, was stuffed with cotton batting to give it a full appearance, including the digits of the fake hand. But, is it critical that the visual object next to the distractor lights was a hand? Perhaps there are critical properties of the fake hand that led to the tactile mislocalizations. If so, there is a chance that these properties can also be found in non-hand objects. The question thus remains as to what it is about the presence of the fake hand that leads to tactile mislocalizations.
If it is the case that the fake hand effect depends on the realistic construction of the hand, then one might expect that the effect would be enhanced if a more realistic hand were used (e.g., mannequin hand). This possibility, however, is minimized by the present finding that the fake hand effect persisted even when the fake hands were no longer directly visible (Experiments 1-2), although it could be the case that the visual cues available were sufficient to allow observers to maintain a mental image of the hand.

Another possibility to consider is that the positioning of the finger and thumb of the fake hand helped to highlight the two distinct elevations of the distractor lights, and this, in turn, influenced tactile mislocalizations. If so, it is likely that any object that highlighted the elevations would produce the same results. Imagine, for instance, that a pair of dentures were positioned to ‘bite’ the distractor lights, such that the upper set of teeth were positioned next to the top light, and the lower set of teeth positioned next to the bottom light. Or, alternatively, imagine that word labels such as ‘top light’ and ‘bottom light’ were assigned to the distractor light elevations. Would these manipulations lead to tactile mislocalizations? Again, although both a possibility, the present findings of a fake hand effect when the digits of the fake hand were no longer visible suggest that drawing attention to the elevations may not be a critical factor.

Would an imagined hand be sufficient for the fake hand effect?

In the Fake Hand conditions of the present study, observers always saw the fake hand as it was put in position, and thus always saw it before it was

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8 Consistent with the elevation proposal, one could argue that the box-cover led to the fake hand effect because it too has a defined top and bottom. But, since the same results were found using the cloth cover, which has a less defined shape, this possibility seems unlikely.
hidden from view. The current thinking on the fake hand effect is that the available visual information is critical for producing the effect. Could it be the case, however, that simply imagining the presence of a fake hand next to the distractor lights would be sufficient for the effect in the absence of any visual cues to its presence? To test this, one could compare the effect across two groups, where one only imagined the fake hand was present, and the other actually saw the fake hand\(^9\). Note that the results of the visibility manipulation in the present study cannot distinguish between whether the partial visual cues to the fake hand’s presence were critical, or whether when the fake hand was hidden, observers were relying on a mental image of the hand.

Is the fake hand effect multisensory or multiinformational?

Consistent with the question above is the idea that the fake hand effect is the result of integrating the available visual and tactile information. According to Pavani et al. (2000), for example, the distractor lights captured the location of the tactile vibrations and this was enhanced by the presence of the fake hand. One might ask, however, whether it was necessary that the distractors were visual (i.e., different modality than the target modality). Another way to think about this is to ask whether the fake hand effect is a product of presenting information in more than one modality (e.g., visual and tactile), or simply the product of presenting multiple sources of information. To test this, one could test whether an additional source of tactile information leads to the same result.

\(^9\) In such an experiment, the group participating in the Imagined Fake Hand condition would always have to participate in the No Fake Hand condition first, as the instructions to imagine a fake hand might interfere with the results of the No Fake Hand condition were it to come first.
What is the Role of Attention in the Fake Hand Effect?

Even though observers are told that the elevation of the distractor lights is irrelevant to their task of localizing the target tactile vibrations, the distractor lights nevertheless influence responses. This suggests that the onset of the lights might capture attention, and do so even when they are separated in space from the tactile vibrations, as evidenced by the measurable CEs at the large vibration-light separation in the present Experiment 1. This raises the question of whether the fake hand effect would be reduced if attention were withdrawn from the lights (e.g., by having observers perform a secondary task such as counting backwards in threes from a given number). Another way of thinking about this is to ask what would happen to the fake hand effect if observers were instructed to attend to the distractor lights rather than ignore them. Although such manipulations would likely change the overall magnitude of the CEs, the relative difference between CEs in the No Fake Hand versus Fake Hand conditions would likely persist since the fake hand effect seems to be something over and above the attention capturing effects of the distractor lights (i.e., CEs increase simply by having the fake hand 'hold' the distractor lights).

In the present Experiment 3, the magnitude of the fake hand effect did not change when observers wore a pair of soft plastic gloves on their hands. It was concluded that providing observers with tactile information that was congruent with the fake hand did not alter the effect. Another interpretation of these results, however, is that wearing the gloves had the added effect of drawing attention to the observer's hands, thereby canceling out any benefits of providing observers with congruent tactile information. There are at least a couple of ways to determine whether this might be the case. One way is to allow observers to
handle samples of soft plastic or to wear the plastic gloves for a short period of time prior to, but not during, the task. Another is to increase attention to the observer's hand by, for example, blowing hot air over it during the task. Either manipulation would allow one to separate the effects of having access to congruent tactile information from those of drawing attention to the observer's hand.

Why is Space an Important Factor in the Fake Hand Effect?

In the present Experiment 1, the fake hand effect was minimized when the distractor lights were separated in space from the tactile vibrations. This finding is consistent with the notion that there are bimodal neurons for the hand that have both a visual and tactile receptive field that are spatially linked such that when the hand moves, the visual receptive field moves with the tactile receptive field (see evidence for bimodal neurons in macaque monkeys in Graziano & Gross, 1993; 1995; Iriki, Tanaka & Iwamura, 1996). In the case of the present study, when there is no horizontal separation between the visual and tactile stimuli, the receptive fields of the bimodal neurons for the hand are likely aligned, resulting in an overadditive neuronal response relative to the case where the visual and tactile information sources are separated in space, and the visual information no longer falls within the visual receptive field of the bimodal neuron.

Are there individual differences in the fake hand effect?

Although the majority of observers in the present study showed the fake hand effect, a small number did not. Additionally, for some observers the effect was larger than for others. What factors are responsible for these individual differences? One possibility is that the observers who showed a smaller fake
hand effect are less susceptible to suggestion than others. To test this, suggestibility tests could be administered at some point during the experiment. If suggestibility turns out to be a contributing factor to the fake hand effect, it would be a natural next step to test the magnitude of the effect in children who are likely more susceptible to suggestion than adults.

**Time-line of the fake hand effect?**

Since Condition (No Fake Hand, Fake Hand) was a within-observer manipulation in Experiment 3, and it was a blocked factor, it was possible to ask whether the fake hand effect was present within the first block of trials, or whether it took some experience with and without the fake hand for the effect to emerge. It was found that the fake hand effect was present within the first two blocks of trials whether the Fake Hand condition came first or followed the No Fake Hand condition\(^{10}\). This is consistent with the findings of Botvinick and Cohen (1998) who reported a fake hand effect within the first three minutes of their manipulation. It is likely that observers need only enough time to recognize the consistent temporal congruency between the visual and tactile information sources before the fake hand effect emerges. It would be interesting to see whether the fake hand effect could be disrupted simply by including trials of both temporally matched and mismatched stimuli together.

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\(^{10}\) A mixed design ANOVA was computed on the RT CEs in Experiment 3 using Condition (No Fake Hand, Fake Hand) as the within-observer factor and Order (Fake Hand first, Fake Hand second) as the between-observer factor. Only the main effect of Condition reached significance, \(F (1, 12) = 9.0, p < .05, \text{MSE} = 252\). Remaining p’s > .15.
References


Table 1  
Descriptive information for each Experiment.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>N</th>
<th>Males</th>
<th>Females</th>
<th>Right Handed</th>
<th>Left Handed</th>
<th>No Corrective Eyewear</th>
<th>Contacts</th>
<th>Glasses</th>
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<td>42</td>
<td>11</td>
<td>31</td>
<td>40</td>
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<tr>
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Table 2

Breakdown of trial types in Experiment 1-5.

<table>
<thead>
<tr>
<th>Experiment/</th>
<th>Within-Observer Manipulations</th>
</tr>
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<tbody>
<tr>
<td>Between Observer</td>
<td>Manipulations</td>
</tr>
<tr>
<td>Exp 1</td>
<td>N = 42</td>
</tr>
<tr>
<td>Condition</td>
<td>Visibility</td>
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<tr>
<td>No Fake Hand</td>
<td>Visible</td>
</tr>
<tr>
<td>Fake Hand</td>
<td>Hidden</td>
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<tr>
<td>Real Hand Baseline</td>
<td></td>
</tr>
</tbody>
</table>

6 blocks (1 block = 96 trials each) = 576 trials  
2 * 3 * 2 = 12 trial types -> 48 trials/type

Exp 2  | N = 13 |
| Condition | T-D Side | Congruency |
| No Fake Hand | Same | Congruent |
| Both Visible | Opposite | Incongruent |
| Both Hidden | |
| One Hidden Hidden Side | |
| One Hidden Visible Side | |

5 blocks (1 block = 96 trials each) = 480 trials  
5 * 2 * 2 = 20 trial types -> 24 trials/type
### Exp 3

<table>
<thead>
<tr>
<th>N = 14</th>
</tr>
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<tbody>
<tr>
<td>Condition</td>
</tr>
<tr>
<td>No Fake Hand</td>
</tr>
<tr>
<td>Fake Hand</td>
</tr>
</tbody>
</table>

- 8 blocks (1 block = 96 trials each) = 768 trials
- $2^2 * 2^2 = 16$ trial types $\rightarrow 48$ trials/type

### Exp 4

<table>
<thead>
<tr>
<th>N = 28</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observer</td>
</tr>
<tr>
<td>Prone</td>
</tr>
<tr>
<td>Supine</td>
</tr>
<tr>
<td>Inconsistent</td>
</tr>
</tbody>
</table>

- 6 blocks (1 block = 96 trials each) = 576 trials
- $3^2 * 2^2 = 12$ trial types $\rightarrow 48$ trials/type

* Response Mapping assignment is Top Tactile Vibration to Toe Pedal Response and Bottom Tactile Vibration to Heel Pedal Response (Top–Toe and Bottom–Heel).

### Exp 5

<table>
<thead>
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<th>N = 28</th>
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<tbody>
<tr>
<td>Same as Experiment 4, except Response Mapping assignment is Top Tactile Vibration to Heel Pedal Response and Bottom Tactile Vibration to Toe Pedal Response (Top–Heel and Bottom–Toe)</td>
</tr>
</tbody>
</table>
Appendix

Experiment 1:

In order to ensure that using difference scores referred to as CEs did not significantly alter the interpretation of the results, additional analyses were computed using the correct RTs as the dependent variable and Congruency (Congruent, Incongruent) as a factor.

Interestingly, most of the effects were observed for the Incongruent trials, but not for Congruent trials. The pattern of results within the Incongruent trials was similar to that observed within the RT CEs, with one exception. When the data was restricted to visible trials where there was no target-distractor separation, the differences in correct RTs for the Real Hand Baseline and Fake Hand condition did not reach significance, whereas CEs were significantly larger in the former condition than in the latter.

A mixed design ANOVA was computed using correct RTs as the dependent variable, Separation (None, Small, Large), Visibility (Visible, Hidden) and Congruency (Congruent, Incongruent) as within-observer factors, and Condition (No Fake Hand, Fake Hand, Real Hand Baseline) as a between-observer factor. Significant interactions were followed up using Simple Interactions or Simple Effects testing, while significant main effects were followed up using Least Significant Difference testing (LSD).

The main effects of Separation \( F(2, 78) = 12.79, \ p < .001 \) and Congruency \( F(1, 39) = 239, \ p < .001 \) were significant. These main effects were tempered by significant interactions of Separation x Condition \( F(4, 78) = 2.90, \ p < .05 \), Congruency x Condition, \( F(2, 39) = 4.30, \ p < .05 \), and Separation x Congruency \( F(2, 78) = 19.13, \ p < .001 \). The three-way interaction of Separation x
Congruency x Condition was also significant \[ F(4, 78) = 5.95, p < .01 \], as was the four-way interaction, \[ F(4, 78) = 2.59, p < .05 \].

First, the four-way interaction was first broken down into its component Condition x Separation x Congruency interaction at each level of Visibility. The three-way interaction was significant only when the limbs were visible, \[ F(4, 78) = 7.99, p < .001 \]. This interaction was broken down into its component Condition x Separation interaction for Congruent and Incongruent trials. The Condition x Separation interaction was significant only on Incongruent trials, \[ F(4, 78) = 6.26, p < .001 \]. When the simple effect of Condition was tested at each level of Separation, it was significant only when there was no horizontal target-distractor separation, \[ F(2, 39) = 6.50, p < .01 \]. Least significant difference testing revealed that RTs were significantly faster in the No Fake Hand condition (577 ms) than in either the Fake Hand (717 ms) or Real Hand Baseline (766 ms) conditions. There was no difference in RTs between the latter two conditions.\(^{11}\)

The simple effect of Separation was also tested at each level of Condition, and was significant only for the Fake Hand \[ F(2, 26) = 6.66, p < .01 \] and Real Hand Baseline conditions \[ F(2, 26) = 12.93, p < .001 \]. Least significant difference testing revealed that for the Fake Hand condition, RTs were significantly slower when there was no target-distractor separation (717 ms) than when the separation was large (628 ms), \( p < .05 \). No comparisons with the small separation (671 ms) reached significance, \( p's > .05 \). For the Real Hand Baseline condition, RTs were significantly slower when there was no target-distractor separation.

\(^{11}\) This finding deviates slightly from the CE data where CEs were significantly larger overall in the Real Hand Baseline condition than in the Fake Hand condition.
separation (766 ms) than when either there was a small (640 ms) or large separation (601 ms), p’s < .01. The remaining comparison did not reach significance, p > .10.

The same overall analysis as that reported above was computed using percentage errors as the dependent variable. Since the error rates were either not significant, or were in the same direction as the correct RTs, speed accuracy tradeoffs were not a concern.

The main effects of Separation [F (2, 78) = 4.42, p < .05] and Congruency [F (1, 39) = 74.39, p < .01] were significant. This was tempered by a significant Separation x Congruency interaction, F (2, 78) = 6.98, p < .01. This interaction was examined by looking at the simple effect of Separation for Congruent and Incongruent trials. Separation was a significant factor only for Incongruent trials, F (2, 78) = 6.40, p < .01. Least significant difference testing revealed that errors were larger overall when there was no target-distractor separation (9%) than for either the small (6%) or large (6%) separations, p’s < .01. The error rates for the latter two separations did not differ from one another, p > .20.

**Experiment 2:**

**Correct RT Analysis # 1:**

Most of the significant effects were observed in the mean Incongruent RTs but not in the mean Congruent RTs. Overall, the pattern of Incongruent RTs was similar to that for the RT CEs with two exceptions. One, the main effect of Distractor Side was not significant in the correct RT data but was significant in the RT CE data. Two, when the data analysis was restricted to opposite-side
target distractor presentations, the main effect of Condition was significant in the Correct RTs but not the RT CEs.

A repeated measures ANOVA was computed on correct RTs using Condition (No Fake Hands, Both Visible, Both Hidden), Target-Distractor Side (Same, Opposite), and Congruency (Congruent, Incongruent) as within-observer factors. The main effects of Congruency \( [F(1, 25) = 75.31, p < .01] \) and Condition \( [F(2, 50) = 5.62, p < .01] \) were significant. These main effects were tempered by a significant Congruency x Condition interaction \( [F(2, 50) = 5.46, p < .01] \), a Congruency x Distractor Side interaction \( [F(1, 25) = 20.54, p < .001] \), and a Congruency x Condition x Distractor Side interaction, \( F(2, 50) = 6.52, p < .01 \).

To better understand the significant three-way interaction, the simple interaction of Condition x Distractor Side was examined separately for Congruent and Incongruent trials. When the data was limited to Incongruent trials, the Condition x Distractor Side interaction was significant, \( F(2, 50) = 5.91, p < .01 \). This was examined further by looking at the simple effect of Condition separately for same and opposite side target-distractor presentations. The simple effect of Condition was significant for same side target-distractor presentations, \( p < .01 \). Simple effects testing revealed that RTs were significantly faster in the No Fake Hands condition (644 ms) than either the Both Visible (764 ms) or Both Hidden (711 ms) conditions, \( F(2, 50) = 8.64, p < .01 \). The comparison between the latter two conditions did not reach significance, \( p > .05 \). When the target-distractor presentations were on opposite sides of fixation, the main effect of

\[\text{12 The main effect of Distractor Side did not reach significance in the correct RT data but was significant in the RT CE data.}\]
Condition was significant, $F(2, 50) = 3.48, p < .05$. Again, RTs were significantly faster in the No Fake Hands condition (629 ms) than either the Both Visible (668 ms) or Both Hidden (669 ms) conditions, $F(2, 50) = 8.64, p < .01$. The comparison between the latter two conditions did not reach significance, $p > .20$.

When the data was limited to Congruent trials, only the main effect of Distractor Side was significant where RTs were faster overall for same side target-distractor presentations (581 ms) than for opposite side presentations (615 ms), $F(1, 25) = 13.62, p < .01$.

**Error data analysis #1:**

The overall analysis reported above was repeated using mean percentage errors as the dependent variable. Significant effects were again seen only on Incongruent trials where the patterns were similar to the Error CEs. In general, the effects were either not significant or were in the direction of the Correct RTs, so speed-accuracy tradeoffs were not a concern.

The main effect of Congruency [$F(1, 25) = 23.78, p < .01$] and Target-Distractor Side [$F(1, 25) = 9.62, p < .01$] were significant. These were tempered by a significant Congruency x Target-Distractor Side interaction, $F(1, 25) = 9.03, p < .01$. This interaction was followed up by looking at the simple effect of Target-Distractor Side for incongruent and congruent trials. The simple effect was significant only on Incongruent trials, where observers made more errors overall for same side (9%) versus opposite side target-distractor presentations (4%), $F(1, 25) = 19.24, p < .01$. Remaining $p > .20$.

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13 This is different from the RT CEs where the main effect of Condition was significant only for same side target-distractor presentations.
Correct RT Analysis # 2:

Significant effects were observed only for the mean Incongruent RTs but not the mean Congruent RTs. Overall, the pattern of Incongruent RTs was similar to that for the RT CEs.

A repeated measures ANOVA was computed on correct RTs using Side of Touch (Hidden, Visible), Distractor Side (Same, Opposite), and Congruency (Congruent, Incongruent) as factors. The main effect of Congruency \( [F (1, 25) = 51.69, p < .01] \) and that of Distractor Side \( [F (1, 25) = 5.34, p < .05] \) were significant. These main effects were tempered by a significant Congruency \times\) Distractor Side interaction \( [F (1, 25) = 18.72, p < .001]\), Side of Touch \times\) Distractor Side interaction \( [F (1, 25) = 12.51, p < .01]\), and a Congruency \times\) Side of Touch \times\) Distractor Side interaction, \( F (1, 25) = 5.45, p < .05\).

To better interpret the three-way interaction, the simple interaction of Side of Touch \times\) Distractor Side was examined separately for Congruent and Incongruent trials. When the data was limited to Incongruent trials, the Side of Touch \times\) Distractor Side interaction was significant, \( F (1, 25) = 9.89, p < .05\). This interaction was further examined by looking at the simple effect of Distractor Side when the tactile stimulus was presented on the side of the visible fake hand or on the side of the hidden fake hand. The simple effect of Distractor Side was significant only when targets and distractors were presented on the side of the visible fake hand, \( F (1, 25) = 20.85, p < .01\). Remaining \( p > .20\). Overall, RTs were slower for same side target-distractor presentations (771 ms) versus opposite side presentations (658 ms).

When the data was limited to Congruent trials, the simple interaction of Side of Touch \times\) Distractor Side did not reach significance, \( F (1, 25) = 1.55, p > .20\).
Error data analysis #2:

The overall analysis reported above was repeated using mean percentage errors as the dependent variable. Significant effects were again seen only on Incongruent trials where the patterns were the same as the Error CEs. Since the effects were either not significant or were in the direction of the Correct RTs, speed-accuracy tradeoffs were not a concern.

The main effects of Congruency \( [F (1, 25) = 22.50, p < .01] \) and Target-Distractor Side \( [F (1, 25) = 14.18, p < .01] \) were significant. These were tempered by significant interactions of Congruency x Distractor Side \( [F (1, 25) = 15.11, p < .01] \) and Congruency x Distractor Side x Side of Touch \( [F (1, 25) = 6.51, p < .05] \). To better understand the three-way interaction, the simple interaction of Side of Touch x Distractor Side was examined for Incongruent and Congruent trials. The simple interaction was significant only on Incongruent trials, \( F (1, 25) = 4.23, p < .05 \). Remaining \( p > .05 \). The simple effect of Distractor Side was examined separately for touch on the occluded or visible side. The simple effect of Distractor Side was significant only when the tactile stimulus was presented on the side of the visible fake hand, where errors were higher for same side (13%) versus opposite side (4%) presentations, \( F (1, 25) = 18.10, p < .01 \).

Experiment 3:

Most of the significant effects were observed in the Incongruent RT data, but not in the Congruent RT data. In the former case, the pattern of results was similar to that observed for the RT CEs.
A four factor repeated-measures ANOVA was computed using correct RTs as the dependent variable, and Condition (No Fake Hand, Fake Hand), Distractor Side (Same, Opposite), Observer Gloves (None, Plastic), and Congruency (Congruent, Incongruent) as factors. The main effects of Condition \[ F(1, 13) = 8.62, p < .05 \] and Congruency \[ F(1, 13) = 27.73, p < .05 \] were significant\(^{14}\). These were tempered by significant interactions of Condition x Congruency \[ F(1, 13) = 10.77, p < .01 \], and Distractor Side x Congruency \[ F(1, 13) = 16.93, p < .01 \]. Both interactions were followed up using simple effects testing. When the analysis was restricted to Congruent trials, only the simple main effect of Distractor Side was significant where RTs were faster overall when the target and distractor were presented to the same side of fixation (569 ms) versus the opposite side (590 ms), \[ F(1, 13) = 34.06, p < .001 \]. When the analysis was restricted to Incongruent trials, both the simple main effects of Condition \[ F(1, 13) = 10.44, p < .01 \] and Distractor Side \[ F(1, 13) = 7.13, p < .05 \] were significant. RTs were faster in the No Fake Hand condition (636 ms) versus the Fake Hand condition (677 ms), and faster when the target and distractor were presented to opposite sides of fixation (643 ms) versus the same side (670 ms).

The overall analysis reported above was repeated using mean percentage errors as the dependent variable. Significant effects were observed mainly on Incongruent trials where the patterns were the same as the Error CEs. Since the effects were either not significant or were in the direction of the Correct RTs, speed-accuracy tradeoffs were not a concern.

\(^{14}\) The main effect of Distractor Side was not significant in the correct RT analysis but was in the RT CE analysis.
The same analysis as that above was computed using errors as the dependent variable. The main effect of Congruency was significant, \( F (1, 13) = 10.53, p < .01 \). This was tempered by significant interactions of Condition x Distractor Side [\( F (1, 13) = 5.54, p < .05 \)], and Congruency x Distractor Side [\( F (1, 13) = 11.73, p < .01 \)]. The four-way interaction also reached significance, \( F (1, 13) = 8.82, p < .05 \). To better comprehend the four-way interaction, it was broken down into the simple three-way interaction of Condition x Congruency x Distractor Side when observers either wore gloves or did not. When observers wore gloves on their hands, the simple three-way interaction did not reach significance, \( F (1, 13) < 1, \text{ns} \). When observers did not wear gloves, the simple three-way interaction was significant, \( F (1, 13) = 8.26, p < .05 \). This was further followed up by looking at the simple Distractor Side x Condition interaction for Incongruent and Congruent trials. The simple interaction was significant only for Incongruent trials, \( F (1, 13) = 6.95, p < .05 \). Remaining \( p > .20 \). The simple effect of Condition was examined for same and opposite side target-distractor presentations, and reached significance only for the former where observers tended to make more errors in the Fake Hand condition (14%) than the No Fake Hand condition (6%), \( F (1, 13) = 4.25, p < .07 \).

**Experiment 4:**

A mixed design ANOVA was computed using correct RT as the dependent variable, Observer Hand Orientation (Prone, Supine) as a between-observer factor, and Fake Hand Condition (No Fake Hands, Prone, Supine), Distractor Side (Same, Opposite), and Congruency (Congruent, Incongruent) as within-observer factors. The main effects of Observer Hand Orientation [\( F (1, 26) \)
= 23.46, p < .01], Congruency [F (1, 26) = 63.97, p < .01], and Fake Hand Condition were significant, F (2, 52) = 5.48, p < .01. These main effects were tempered by significant interactions of Congruency x Distractor Side [F (1, 26) = 25.16, p < .01], Fake Hand Condition x Distractor Side [F (2, 52) = 4.11, p < .05], and Congruency x Fake Hand Condition x Observer Hand Orientation [F (2, 52) = 6.83, p < .01].

The Fake Hand Condition x Distractor Side interaction was followed up by looking at the simple main effect of Fake Hand Condition for same and opposite side target-distractor presentations. The simple main effect was significant only for same side target-distractor presentations, F (2, 52) = 8.0, p < .01. Mean RTs were slower overall when the fake hand was prone (748 ms) than either supine (701 ms) or absent (697 ms), p’s < .05. The comparison between the latter two was not significant, p > .20.

The three-way interaction was followed up by examining the simple interaction of Fake Hand Condition x Congruency for prone and supine observer hand postures. When the observer’s hands were prone, the simple interaction was significant, F (2, 26) = 5.14. This was further examined by looking at the simple main effect of Fake Hand Condition for congruent and incongruent trials. The simple main effect was significant only in the latter case, F (2, 26) = 8.19, p < .01. RTs were slower when the fake hands were prone (662 ms), than when either supine (622 ms) or absent (616 ms), p’s < .01. When the observer’s hands were supine, the simple interaction of Fake Hand Condition x Congruency was significant, F (2, 26) = 3.80, p < .05. The simple main effect of Fake Hand

15 The main effect of Distractor Side was not significant in the correct RT data but was in the RT CE data.
Condition was significant only on Congruent trials, $F(2, 26) = 3.40, p < .05$. RTs were significantly slower when the fake hands were prone (838 ms) than supine (778 ms) or absent (776 ms), $p$'s < .05.

The overall analysis reported above was repeated using mean percentage errors as the dependent variable. Significant effects were observed only on Incongruent trials where the patterns were the same as the Error CEs. Since the effects were either not significant or were in the direction of the Correct RTs, speed-accuracy tradeoffs were not a concern.

The main effects of Congruency [$F(1, 26) = 51.77, p < .01$] and Distractor Side [$F(1, 26) = 6.59, p < .05$] were significant. These were tempered by a significant Congruency x Distractor Side interaction, $F(1, 26) = 22.68, p < .01$. This was followed up by examining the simple effect of Distractor Side for Incongruent and Congruent trials. The simple effect was significant only on incongruent trials where observers tended to make more errors on same side (11%) versus opposite side target-distractor presentations (8%), $F(1, 26) = 19.20, p < .01$.

**Experiment 5:**

A mixed design ANOVA was computed using correct RTs as the dependent variable, Observer Hand Orientation (Prone, Supine), and Digit-Response Mapping (top-toe & bottom-heel, top-heel & bottom-toe) as between-observer factors and Congruency (Congruent, Incongruent), Fake Hand Condition (No Fake Hand, Consistent, Inconsistent), and Distractor Side (Same, Opposite) as within-observer factors. The main effect of Congruency was significant, $F(1, 52) = 58.99, p < .01$. This was tempered by significant
interactions of Congruency x Observer Hand Orientation \[F (1, 52) = 9.13, p < .01\], Congruency x Digit-Response Mapping \[F (1, 52) = 18.22, p < .01\], Congruency x Condition \[F (2, 104) = 4.52, p < .05\], Congruency x Distractor Side \[F (1, 52) = 14.09, p < .01\], Congruency x Observer Hand Orientation x Digit-Response Mapping \[F (1, 52) = 7.89, p < .01\], Congruency x Distractor Side x Observer Hand Orientation \[F (1, 52) = 10.91, p < .01\], Congruency x Distractor Side x Digit-Response Mapping \[F (1, 52) = 4.68, p < .05\], Congruency x Distractor Side x Observer Hand Orientation x Digit-Response Mapping \[F (1, 52) = 7.34, p < .01\]. The Condition x Distractor Side x Observer Hand Orientation interaction was also significant, \(F (2, 104) = 3.23, p < .05\).

The four-way interaction was examined by looking at the simple interaction of Distractor Side x Observer Hand Orientation x Digit-Response Mapping for Incongruent and Congruent trials. The interaction was significant only for Incongruent trials, \(F (1, 52) = 7.15, p < .05\). The simple interaction of Distractor Side x Digit-Response Mapping was examined for prone and supine observer hand orientations. It was significant only when the observer’s arms were supine, \(F (1, 26) = 8.19, p < .01\). The simple effect of Distractor Side approached significance only for the top-heel & bottom-toe mapping, where observers were faster to localize the target when the distractor was presented to the same side (622 ms) versus the opposite side of fixation (646 ms), \(F (1, 13) = 4.51, p < .06\).

The Condition x Distractor Side x Observer Hand Orientation interaction was examined by looking at the simple interaction of Condition x Observer Hand Orientation for same and opposite side target-distractor presentations. The interaction was significant only for same side target-distractor presentations,
F (2, 104) = 4.30, p < .05. The simple effect of Condition was examined for prone and supine observer arm postures. When the observer's arm was prone, the simple main effect of Condition approached significance, F (2, 54) = 2.51, p < .10. Mean RTs in the Consistent Fake Hand condition (757 ms) were significantly slower than the RTs in the Inconsistent Fake Hand condition (716 ms) but not the No Fake Hand condition (730 ms). When the observer's arm was supine, the simple main effect of Condition approached significance, F (2, 52) = 2.68, p < .10. Mean RTs were significantly slower in the Inconsistent Fake Hand condition (759 ms) than the No Fake Hand condition (724 ms), but did not differ from the Consistent Fake Hand condition (729 ms).

The same overall analysis as that reported above was computed using mean percentage error as the dependent variable. The main effects of Congruency [F (1, 52) = 51.61, p < .01] and Distractor Side [F (1, 52) = 6.80, p < .05] were significant. These were tempered by significant interactions of Congruency x Digit-Response Mapping [F (1, 52) = 13.36, p < .01], Congruency x Distractor Side [F (1, 52) = 15.47, p < .01], Congruency x Distractor Side x Digit-Response Mapping [F (1, 52) = 6.52, p < .05]. The Observer Hand Orientation x Digit-Response Mapping interaction was also significant, F (1, 52) = 6.99, p < .05.

The three-way interaction was examined by looking at the simple interaction of Distractor Side x Digit-Response Mapping for Congruent and Incongruent trials. The simple interaction approached significance only on the incongruent trials, F (1, 52) = 2.97, p < .10. The simple main effect of Distractor Side was significant only for a top-toe & bottom-heel mapping assignment, F (1, 26) = 19.20, p <.01. Error CEs were larger overall on the same side (11%) versus the opposite side (8%).
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