THE INFLUENCE OF HAND POSITION ON PRIOR ENTRY

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Abstract

Attended information is perceived quicker than unattended information. This is known as prior entry. When making judgments on the temporal order of two successive stimuli, performance is influenced based on attention. We were interested in whether this same attentional shift would occur when we adopt a crossed hands posture. Typically when making these tactile temporal order judgments, performance declines when the hands are crossed. This may be due to a greater influence of the external environment in the crossed posture. We investigated this by providing an exogenous visual cue at one or both of the hands prior to making judgments about the temporal order of two successive vibrations. This was completed with the hands crossed and uncrossed. In Experiment 1 responses were to which stimulus occurred first. In Experiment 2 participants responded to which stimulus occurred second. Changing the response requirement did not influence overall performance. In both experiments we observed prior entry that was in the same direction for both crossed and uncrossed postures. The size of the prior entry effect was larger when the hands were crossed. We remap tactile information quickly to external coordinates, however we are less certain of the hand's location.

Acknowledgements

If you had told me I would be completing my M.Sc. at McMaster a few years ago, I would probably have laughed. Staying here for my M.Sc. and now Ph.D. was never part of my plan. But I am glad that plan changed, and I have Michelle Cadieux and David Shore to thank. Michelle instilled my love for research, especially in multisensory perception. David offered me the chance to keep pursuing this interest as a graduate student. I will forever appreciate all the time and effort you put in to make me the researcher I am today.

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List of Abbreviations and Symbols

ANOVA	Analysis of variance
ISI	Inter-stimulus interval
LED	Light-emitting diode
PSS	Point of subjective simultaneity
SOA	Stimulus onset asynchrony
TOJ	Temporal order judgment

Declaration of Academic Achievement

The idea for this study was conceived by KU and DIS. Data for these experiments were collected by KU and Anthony Battaglia. Graphs were created by KU, and all analysis was conducted by KU. Under the supervision of DIS, KU wrote the manuscript.

Chapter 1: Introduction

We rely on our senses to provide a clear depiction of our environment. We use visual information to see when a friend sends us a message, we use auditory information to hear when someone calls our name, and we use touch to gain information on the texture of a surface. We also use our senses to help us determine the timing of events. This helps us know how long before that friend is at our side, or when to brake before we hit the car in front. We integrate all this information to form an accurate picture of our environment. However, our senses may not provide as accurate a portrayal as we hope. When we are attending to a specific location or modality, information from that source is perceived sooner (Driver & Spence, 1998; Kennett, Eimer, Spence, & Driver, 2001; Shore, Spence, & Klein, 2001; Spence, Crombez & Moseley, 2009; Spence & Driver, 1997; Spence & Parise, 2010; Spence, Pavini, & Driver, 2000; Spence, Shore, & Klein, 2001; Titchner, 1908; Van Damme, Gallace, Yates & Nicholls, 2009). The consequence is the timing we perceive might not be the actual timing of the events. We were interested in exploring the role of attention within the tactile modality. Specifically we investigated whether this speeded tactile perception would occur when the hands are crossed over the midline.

The knowledge that attention could influence the time our senses perceive information was first observed by astronomers in the 18th and 19th centuries. While timing celestial events astronomers would count the seconds, based on the number of clicks from a watch, as the star crossed the telescope lens. Differences between the reports of astronomers led to the personal equation, the time to be added or subtracted from each observer to equate their calculations (Bessel, 1882). This was the first evidence that attending to one modality influenced perception in another modality. Removing the personal equation was simple. Instead of one observer, use two observers: one to make a sound when the star crosses the lens, and the other to track when the sound occurred. In this situation each observer's attention was focused on only one modality, eliminating any attentional biases.

Since then, attention has been shown to influence perception in many other situations. When attending to a location in external space we are quicker to perceive stimuli at an attended location compared to a non-attended location (Driver & Spence, 1998; Kennett et al., 2001; Spence & Driver, 1997; Spence et al., 2001). Elevation judgments to a tactile stimulus were faster when a preceding cue (auditory or visual) was presented on the same side as the required response (Spence, Nicholls, Gillespie, & Driver, 1998). This benefit in response time on the attended side is present when audition, vision, or touch is the cue and any modality is the target (Spence & Driver, 1997). These previous studies used an exogenous cue to draw attention. The same crossmodal attention effects can be found with an endogenous cue; however, the magnitude of the effect is smaller (Driver & Spence, 1998). Attentional benefits are crossmodal.

Attentional cues also influence the perception of temporal order (Shore et al., 2001; Spence et al., 2001; Spence & Parise, 2010; Van Damme et al., 2009; Yates & Nicholls, 2009). In the context of temporal order this advantage is known as prior entry. In a typical prior entry experiment participants judge the order of two successive stimuli. The interval between the two stimuli, the stimulus onset asynchrony (SOA), is varied.

Attention is directed either to a particular side or to a particular modality. This can be accomplished endogenously, by altering the likelihood of a certain response (Spence, Shore & Klein, 2001), or exogenously, by a cue preceding the stimuli (Yates & Nicholls, 2009). For example, participants were presented with a visual and tactile stimulus, one on each hand, and asked to indicate which occurred first (Spence et al., 2001). Responses were made either to the modality that was presented first, or to the hand that was stimulated first. Attention was manipulated endogenously by increasing the proportion of responses occurring first on one hand or in one modality. Prior entry is typically measured by the point of subjective simultaneity (PSS), the interval between two stimuli for them to be perceived as occurring together. This is calculated as the SOA where participants are equally likely to indicate either stimulus as occurring first. Shifts in the PSS indicate the magnitude and direction of prior entry. When attending to one modality, the PSS was shifted towards the other modality, indicating that the other modality needed to be presented earlier in time for the two presentations to be perceived as simultaneous. The difference between the PSS and the point where the two stimuli are simultaneous is the prior entry effect. The same results were found when attending to a specific hand. Prior entry has also been observed using exogenous cues. A picture representing a physical threat, general threat, or no threat was presented on a computer screen above one of the participant's hands (Van Damme et al., 2009). The participant then received two tactile stimuli, one to each hand, and indicated which occurred first. Stimuli presented on the same side as a physically threatening image were perceived sooner than those presented with a general threat or no threat. Additionally, images displaying a general threat facilitated perception of the tactile stimulus to a greater degree than the no threat images. The degree to which attention is shifted towards a particular location alters the magnitude of prior entry.

One alternative explanation for the results of prior entry studies is response bias. When asked to report which of two stimuli occurred first, participants reported the attended modality (Frey, 1990). Upon switching the task to report which stimulus occurred second, participants still reported the attended modality. Changing the response requirements reversed the direction of prior entry, raising the question of whether prior entry is truly a perceptual effect or an attentional bias. However, more recent studies still report finding prior entry even when controlling for response bias (Shore et al., 2001; Spence et al., 2001; Stelmach & Herdman, 1991). For example, the use of an orthogonal cueing paradigm, whereby participants attend to a specific modality and respond to a side of space, reduces the possibility of potential response bias. Under these conditions prior entry was still observed.

In previous studies on prior entry, hands were placed in an uncrossed posture. Crossing the hands over the midline influences the ability to determine temporal order (Azañón & Soto-Faraco, 2007; Cadieux, Barnett-Cowan, & Shore, 2010; Craig & Belser 2006; Drew, 1896; Heed, Backhaus, & Roder, 2012; Holmes, Sanabria, Calvert, & Spence, 2006; Kobor, Furedi, Kovacs, Spence, & Vidnyanszky, 2006; Roberts & Humphreys, 2008; Roder, Rosler, & Spence, 2004; Shore, Spry, & Spence, 2002; Wada, Yammamoto, & Kitazawa, 2004; Yamamoto & Kitazawa, 2001). When the hands are crossed, elevation judgments to tactile stimuli are faster following a visual cue on the same side of external space (Driver & Spence, 1998). Specifically, a visual cue on the left facilitates tactile judgements on the right hand (which is now on the left side), and a visual cue on the right facilitates tactile judgments on the left hand (which is now on the right side). This suggests that we remap tactile events into external coordinates to accommodate different body postures (Azañón, Longo, Soto-Faraco & Haggard, 2010). We were interested in how a crossed posture would influence prior entry.

In this paper we will discuss two experiments designed to investigate visually induced tactile prior entry with the hands crossed, and uncrossed. Participants were presented with a brief flash of light near one or both hands, and then presented with two vibrations, one to each hand. This was completed with their hands uncrossed and crossed. In experiment 1 responses were to which hand received the first vibration. In experiment 2 participants indicated which hand vibrated second. We hope by conducting both a "which came first" and "which came second" task to be better able to differentiate the contributions of prior entry and response bias to performance.

Chapter 2: Experiment 1 – Which Came First?

2.1 Methods

2.1.1 Participants

Twenty right-handed participants (10 males), average age of 18.7, were recruited from the McMaster University undergraduate subject pool. One course credit was provided for their participation. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. Written informed consent was provided prior to participation.

2.1.2 Apparatus and Stimuli

Participants were sitting at a table (height of 73.7 cm) with their hands placed 18 cm apart. Stimulation and responses were delivered and collected from a small wooden box with a Plexiglas top. A 2 cm diameter hole was cut in the top for participants to place their thumb on the vibrator. Vibrations were delivered with an Oticon-A (100 Ohm) bone conduction vibrator (width: 1.6 cm, length: 2.4 cm). The vibrators were driven by an amplified 250 Hz sine wave, set by the experimenter to be comfortable and clearly suprathreshold. Mounted beneath the vibrators were response buttons. At the top of the cube a yellow Light-Emitting Diode (LED) (diameter: 0.5 cm, height: 0.8 cm) was mounted. All stimulation was controlled by a set of read-relays connected to the parallel port of a DELL Dimension 8250 running Windows XP software. Matlab was used to administer the stimulation and collect responses. Participants wore headphones playing white noise during the experiment to mask the sounds produced by the tactile vibrators.

2.1.3 Procedure

Participants held one wooden cube in each hand, with their thumbs in contact with the vibrators. Participants first completed two practice blocks, each with 24 trials. The first block was completed with their hands uncrossed, and the other with their hands crossed over the midline. The experimenter was in the room during the practice trials to provide feedback and answer any questions. The participant then completed 12 experimental blocks of 72 trials. The experimenter would start each block of trials and leave the room, coming in after each block to check on the participant and start the next block. Hand position alternated each block between crossed and uncrossed. The starting hand position was counterbalanced across participants.

Each trial began 800 ms after the participant's previous response. On each trial a light flashed for 50 ms on the left, right, or both cubes. After a 100 ms interstimulus interval (ISI) two 20 ms vibrations, one to each thumb, were delivered. The light occurred randomly at two possible locations, and was not predictive of the correct response. The two vibrations were separated by one of a fixed set of stimulus onset asynchronies (SOA): ±400, ±200, ±100, ±50 ms, where negative SOAs indicate the vibration was to the left hand first. This resulted in 18 trials for each light position per SOA for each hand posture. Responses were made to which hand vibrated first. Participants responded by pressing down on the corresponding vibrator. If no response was made within three and a half seconds of the second vibration, the participant timed out. In this situation both buttons vibrated three times, and participants pressed both buttons in order to move on. These trials and trials where participants responded in less than 100 ms were removed before analysis.

2.2 Results

The proportion of right first responses at each SOA was calculated for each light and hand condition. Using a standard normal distribution these values were converted to z-scores. The slope and intercept were calculated on the normalized data and used to compute the PSS. This was taken as the SOA where participants were equally likely to indicate a "right first" or "left first" response (see **Table 1** for PSS values). If the PSS was not within the range of SOAs used in the task, we took the closest SOA used in our task and replaced the participant's SOA with that value. For instance, if the participant had an extreme positive PSS, the value was replaced with 400 ms; if the PSS was an extreme negative, the value was replaced with -400 ms. This replacement occurred for 8 participants when the hands were crossed. Within those 8 participants, 1 uncrossed value was replaced. These values were then submitted to a 2x3 Analysis of Variance (ANOVA) with the within-participant factors of hand position (crossed vs. uncrossed) and light condition (left hand vs. right hand vs. both hands) (**Figure 1**). Greenhouse-Geisser corrections were made where appropriate. Adjusted *p*-values and unadjusted degrees of freedom were reported. The PSS did not differ between the uncrossed and crossed hand positions ($F(1,19) = 2.81$, $p = .110$). There was a main effect of light condition ($F(1,38) = 83.97$, $p < .001$) where the difference between all light conditions was significant (Left Hand: M = 193.8 ms; Both Hands: M = 54.5 ms; Right Hand: M = -207.0 ms). A significant interaction between hand position and light condition was observed ($F(1,38) = 14.79$, $p < .001$). The influence of the light was greater when the hands were crossed than uncrossed.

In order to determine whether prior entry differed for the crossed compared to uncrossed posture, we calculated half the difference between the right hand light PSS from the left hand light PSS for each hand posture. This provided one number for each hand posture that signified the effect of receiving a visual cue on TOJ performance. A paired sample *t*-test showed the influence of the light was significantly different when the hands were crossed (M = 281.6 ms, SD = 123.3 ms) compared to uncrossed (M = 119.1 ms, SD = 88.8 ms; $t(19) = 4.56$, $p < .001$).

2.3 Discussion

Performance on the TOJ task differed, as measured with the PSS, based on whether participants saw a light near their left hand, right hand, or both hands. When a light occurred on the left hand the PSS was shifted to the right, indicating the right vibration needed to occur earlier in time to be perceived as simultaneous. The opposite was true for a light on the right hand, where the left vibration preceded the right for a simultaneous judgment. The amount the second vibration needed to precede the first was larger in the crossed posture than uncrossed postures, suggesting prior entry is influenced by hand position.

One alternative explanation for the observed PSS shift is response bias. When unsure of the correct answer, participants could be using the location of the light to select their response. Previous TOJ studies without visual cues show lower accuracy when the hands are crossed (Yammamoto & Kitazawa, 2001; Shore et al., 2002). Participants may be more biased by the light cue when the hands are crossed. Indeed the variance in crossed hands performance is greater than for uncrossed hands.

Hand Position	Light		
	Left	Right	Both
Crossed	274.0 (189.4)	-289.2 (159.8)	120.0 (197.8)
Uncrossed	113.5 (93.6)	-124.7 (115.5)	-11.0 (65.7)

Table 1: Mean PSS and standard deviations (in ms) for each light and hand condition in Experiment 1.

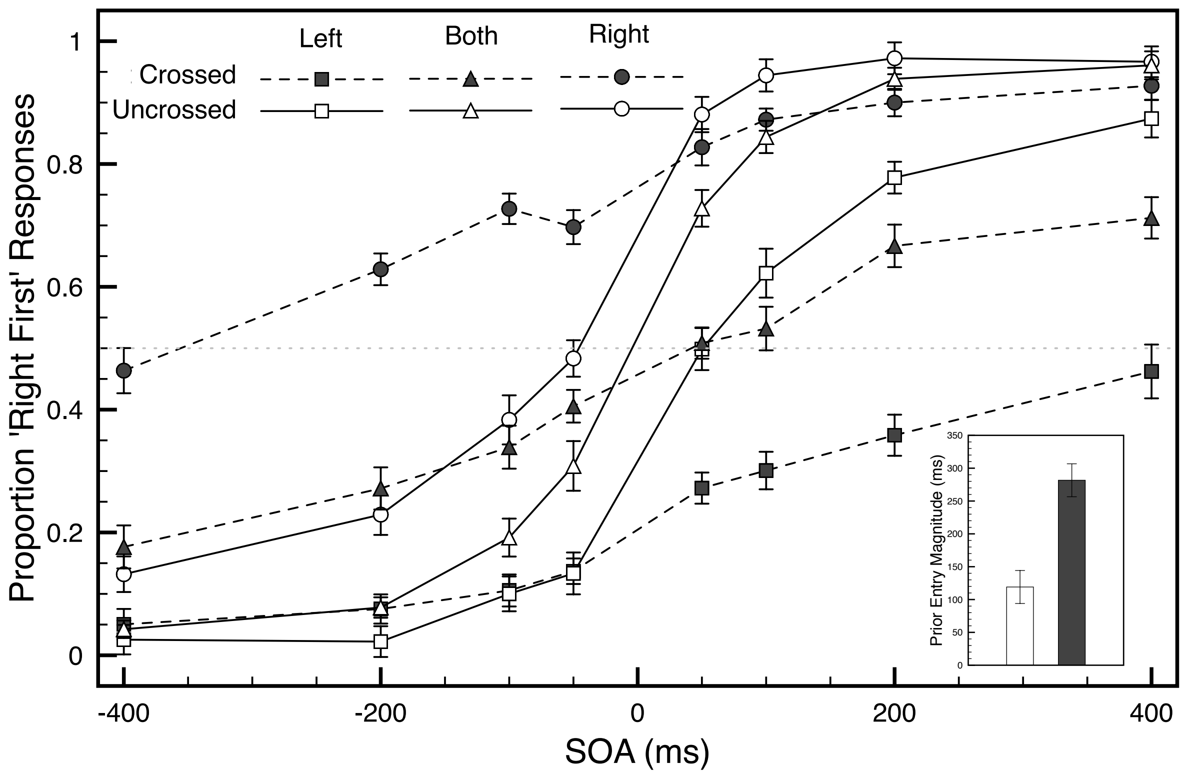

Figure 1: Overall data from Experiment 1. Within-participant manipulations of light condition and hand posture. Participants indicated which hand vibrated first. The average proportion of 'right first' responses was calculated for each participant at each SOA. Error bars represent within-participant standard error of the mean (Cousineau, 2005; Morey, 2008). The bar graph depicts half the PSS difference between the left and right light.

Chapter 3: Experiment 2 – Which Came Second?

In order to determine whether the difference in prior entry between the crossed and uncrossed posture was due to response bias, we repeated the study but now asked participants to select the second vibration. In this situation if participants are biased towards the light it should shift the PSS in the opposite direction, making any potential differences harder to observe.

3.1 Methods

3.1.1 Participants

Twenty right-handed participants (10 males), average age of 19.2, were recruited from the McMaster University undergraduate subject pool. One course credit was provided for their participation. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. Written informed consent was provided prior to participation.

3.1.2 Apparatus and Stimuli

This was identical to Experiment 1.

3.1.3 Procedure

The same procedure was used as Experiment 1 except participants now responded to which hand vibrated second.

3.2 Results

PSS scores (see **Table 2**) were submitted to a 2x3 ANOVA with the within-participant factors of hand position (crossed vs. uncrossed) and light condition (left hand vs. right hand vs. both hands) (**Figure 2**). Greenhouse-Geisser corrections were made where appropriate, adjusted *p*-values and unadjusted degrees of freedom were reported. We replaced any PSS values outside the range of SOAs used in the task. This replacement occurred for 3 participants both the crossed-hands and uncrossed-hands condition. There was no significant difference between the uncrossed and crossed hand positions ($F(1,19) = 0.06$, $p = .806$). There was a main effect of light condition ($F(1,38) = 34.5$, $p < .001$) where the difference between all light conditions was significant (Left Hand: M = 139.8 ms; Both Hands: M = -9.3 ms; Right Hand: M = -96.0 ms). A significant interaction between hand position and light condition was observed ($F(1,38) = 8.2$, $p = .001$) revealing the influence of the light was larger in the crossed than uncrossed posture.

When looking at the PSS difference score between the right and left hand light, a paired sample *t*-test revealed a significant difference between hand postures. The difference when the hands were crossed (M = 165.2 ms, SD = 124.8 ms) was greater than the difference in the uncrossed posture (M = 70.6 ms, SD = 35.0 ms; $t(19) = 3.64$, $p = .002$)

3.3 Discussion

We replicated the shift in PSS based on whether the light occurred on the left or right hand. When a light occurred on the left hand, the right vibration needed to occur earlier to be perceived as simultaneous. The opposite was true for a light on the right hand. By using a ‘which came second’ task we hoped to reduce the variability observed in performance. Under these conditions any response bias should now make it harder to find group differences. We still observed a shift in PSS that was different across the two hand postures. The magnitude of prior entry was larger when the hands were crossed.

Hand Position	Light		
	Left	Right	Both
Crossed	197.3 (142.3)	-133.1 (174.9)	-35.9 (129.5)
Uncrossed	82.3 (47.8)	-58.9 (39.8)	17.3 (32.4)

Table 2: Mean PSS and standard deviations (in ms) for each light and hand condition in Experiment 2.

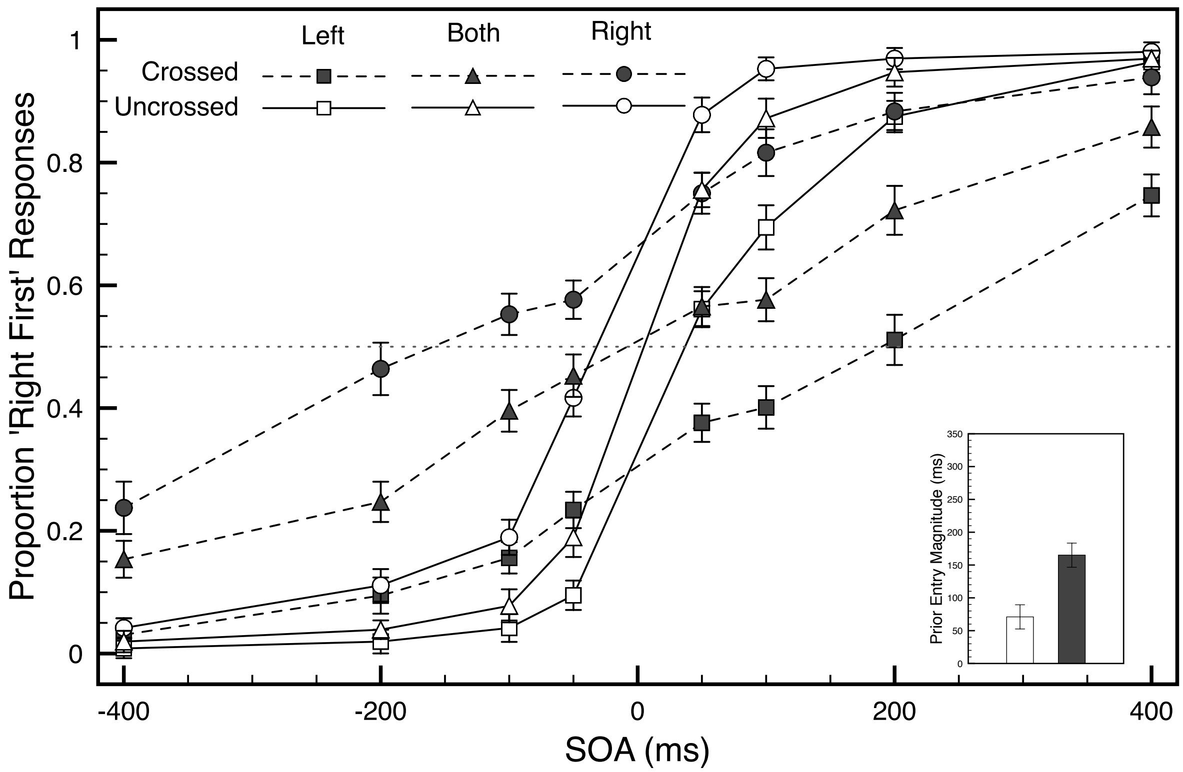

Figure 2: Overall data from Experiment 2. Within-participant manipulations of light condition and hand posture. Participants indicated which hand vibrated second. The average proportion of 'right first' responses was calculated for each participant at each SOA. Error bars represent within-participant standard error of the mean (Cousineau, 2005; Morey, 2008). The bar graph depicts half the PSS difference between the left and right light.

Chapter 4: General Discussion

In Experiment 1 we used a “which came first” task and found the magnitude of prior entry was greater when the hands were crossed than uncrossed. Response bias may have contributed to the size of the effect. Under a “which came first” response condition, response bias and prior entry would both shift the PSS in the same direction. If participants were using the location of the light to formulate their response, then our value for prior entry would be inflated. In Experiment 2 we reversed the direction of response bias by using a “which came second” task. Now if participants used the light to make their response, the PSS should be in the opposite direction of the first experiment. In this case, response bias and prior entry would each shift the PSS in opposite directions. If the PSS shift were due to prior entry, this experiment would make it even harder to measure. With the new task demand, the PSS shifted in the same direction as Experiment 1. Moreover, prior entry was still significantly larger when the hands were crossed.

If there were absolutely no response bias, then we would expect the prior entry magnitude to be identical across both experiments. Any response bias in the “which came first” experiment should be completely opposite in the “which came second” experiment. Therefore if we take the average of our prior entry values from both experiments, we should obtain an estimate of the prior entry effect free of response bias. The true prior entry effect is 223.4 ms when the hands are crossed and 94.9 ms when the hands are uncrossed (**Figure 3**). Response bias can be estimated as half the difference between the “which came first” and “which came second” experiments. Based on this calculation, response bias influenced crossed performance by 58.2 ms and uncrossed performance by 24.3 ms.

One factor that could affect our estimate of the true prior entry effect is the method we used to calculate the PSS. As mentioned previously, any PSS value outside the range of SOAs tested was replaced with the extreme SOA value. This replacement occurred more often in the crossed-hands condition, which might result in an underestimation of the true prior entry value in this posture. Even with this replacement we still found a greater prior entry effect with the hands crossed compared to uncrossed.

We have shown that an exogenous light attracts attention and speeds perception for tactile stimuli in the same spatial location. These findings corroborate those of Van Damme and colleagues (2009) who showed speeded perception for tactile stimuli when images were presented near the hand. We expanded these findings by exploring what happens to this prior entry effect by crossing the hands over the midline. When the hands are crossed tactile information is remapped into external spatial coordinates (Azañón, Longo, Soto-Faraco & Haggard, 2010; Shore et al., 2002). This external reference for the tactile stimulus is activated very quickly. Therefore the exogenous light cue influences the hand located on the same side of space as the light (i.e., a light on the right influenced the left hand). If touch were not remapped to external coordinates the same light cue would influence the opposite location (ex. a light on the right would influence the right hand).

The effect of the light was greater when the hands were crossed. On a typical tactile TOJ task, crossing the hands results in lower temporal order accuracy (Shore et al., 2002; Yammamoto & Kitazawa, 2001). The prevailing theory states that when the hands are crossed the two reference frames used to locate touch (internal and external reference frames) are in conflict (Shore et al., 2002). We incorrectly resolve this conflict using information from the external frame. An exogenous light may cause participants to rely even more on this external information, thereby shifting the PSS to a greater degree in the crossed posture.

It remains to be seen whether other types of cues have the same influence on crossed-hands prior entry. Future studies could investigate whether auditory or tactile cues produce crossed-hands prior entry, and whether the magnitude is the same. Our external reference frame is considered to be largely visual (Roder et al., 2004). If in the crossed posture we are more influenced by the external reference frame, then a visual cue would produce a larger prior entry effect than an auditory or tactile cue. A similar logic could be applied to endogenous cues. These cues would not activate the external reference frame to the same degree, and may not produce as large a prior entry magnitude. Another future line of research could be to manipulate the ISI. The current study used a short ISI between the light and the first vibration. Manipulations of this ISI may provide further insight into the time course of prior entry. Introducing different ISI's would allow us to explore the maximum temporal gap where we can still observe prior entry. With further increases to the ISI we may even find inhibition of return.

The present study showed that an exogenous light could induce prior entry on a tactile TOJ when the hands were crossed and uncrossed. We found a larger prior entry effect when the hands were crossed, which we believe to be driven by less confidence on the location of the hands in this posture. The use of both a “which came first” and “which came second” task provides some confidence that the effect was not driven solely by response bias. Prior entry crosses the midline.

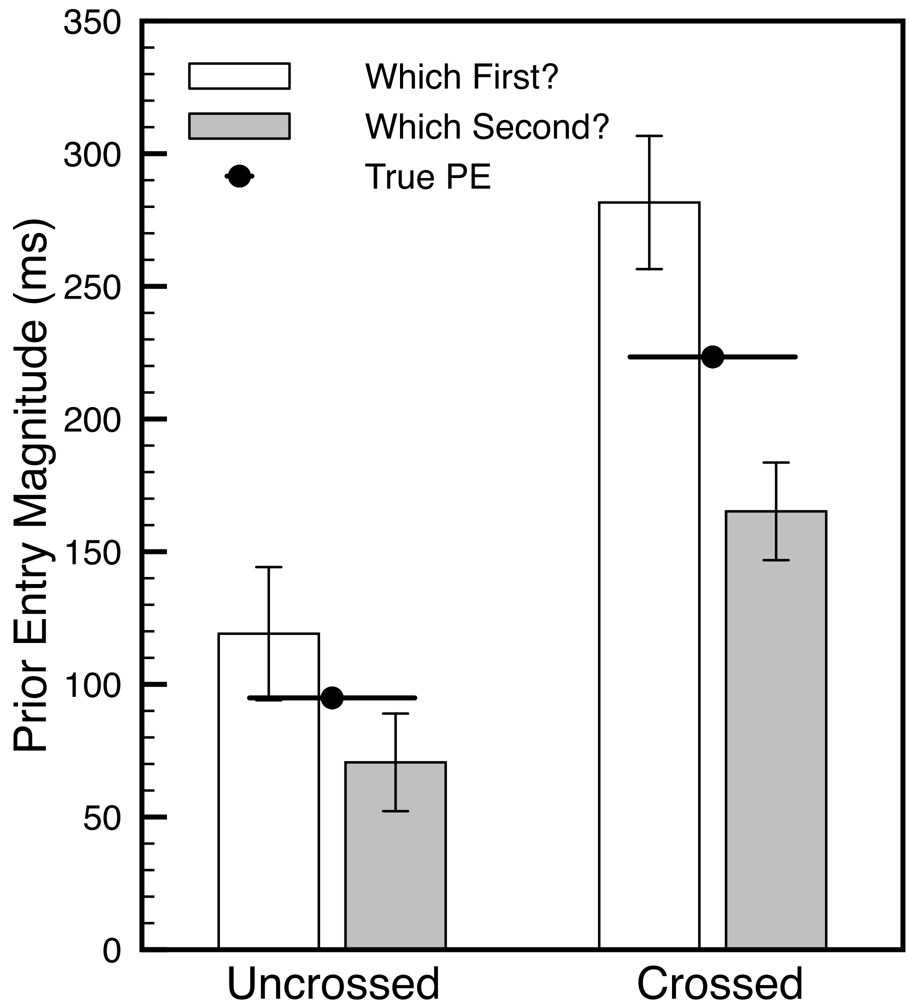

Figure 3: An across experiments comparison. The prior entry magnitude for both experiments is displayed here. The horizontal line indicates the estimated true prior entry, when response bias is removed. Error bars represent within-participant standard error of the mean (Cousineau, 2005; Morey, 2008).

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