Do visual body-ownership cues modulate visuo-tactile temporal order judgements? An investigation in non-synaesthetes and mirror-touch synaesthetes

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Summary

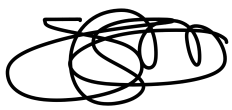
To accurately perceive oneself in a complex multisensory environment, the brain has to determine which unimodal signals originated from its own body and should therefore be integrated. It is currently debated if visual body-ownership cues such as object form and orientation interact, and if visual plausibility increases the effects of various multisensory signals being integrated. In this thesis, I investigated the effects of visual body-ownership cues on visuo-tactile temporal perception in both non-synaesthetes and mirror-touch synaesthetes using a temporal order judgement (TOJ) task.

Each participant viewed videos of a touch being applied to visual stimuli that were either plausible or implausible for his or her right hand (hand oriented plausibly, hand rotated 180 degrees, sponge). On each trial, a touch was also applied to the participant's own hand at varying stimulus onset asynchronies (SOAs) relative to the visual touch. Participants judged which stimulus came first: viewed or felt touch. I tested whether visual body-ownership cues affect temporal binding and the size of the temporal interval between visual and tactile stimuli participants can reliably notice ('just noticeable difference' - JND).

Bayesian analyses revealed that plausibility of object form and orientation do not affect visuo-tactile temporal perception in either non-synaesthetes or mirror-touch synaesthetes. I discuss the implications of these findings in relation to understanding body perception and mirror-touch synaesthesia.

Author’s statement

I declare that this work is entirely my own except where I have given full documented references to the work of others, and that the material contained in this thesis has not been submitted previously as an exercise for a degree at this university or another institution. This project was approved by the Macquarie University Ethics Committee (Reference No: 5201700508).



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Chapter 1: Introduction

To successfully interact with the environment we must distinguish our bodies from external objects. Being able to correctly localise and identify oneself in a complex environment is clearly an evolutionary advantage (Graziano & Botvinick, 2002). The brain constantly receives a stream of sensory information, both from within the body and from outside. Popular theories for body perception state that we integrate information from different senses to identify ourselves, establish a sense of body-ownership and keep track of our current location (Blanke, 2012; Botvinick, 2004; Ehrsson, 2012; Kilteni, Maselli, Kording & Slater, 2015; Tsakiris, 2010). This is a challenging task as body representations need to be dynamically updated due to movement of body parts and morphological changes including growth and damage.

Research into how the brain integrates multisensory information in own-body contexts provides important insight into the cognitive processes that underlie body perception. This is also relevant for disturbed body perception in clinical conditions such as somatoparaphrenia, a condition where one denies ownership over a limb or an entire side of the body (Vallar & Ronchi, 2009) and anorexia nervosa (e.g., Gaudio, Brooks & Riva, 2014; Zopf, Contini, Fowler, Mondraty & Williams, 2016). Individuals in whom multisensory information is processed differently may in turn provide an opportunity to test current theories for multisensory perception. Mirror-touch synaesthetes (MTS), for instance, experience a feeling of touch on their own bodies when they see someone else being touched. In this population, integration of multisensory information might be differentially influenced by visual information in relation to touch (e.g., Davies, White & Davies, 2013).

In this thesis, I investigate the role of visual information on the integration of visual and tactile stimuli in own-body contexts. This first chapter outlines the idea that the representation of the body crucially relies on multisensory integration. To support the claim that body representation is a multisensory construct, I draw on literature from the rubber hand illusion (RHI), a useful paradigm to manipulate limb-ownership which has taught researchers about the interaction between spatial, temporal and visual cues for the emergence of a sense of ownership. The interaction of these body-ownership cues can be explained in a framework of Bayesian integration, which proposes that body-ownership arises due to an above-chance probability that the incoming sensory inputs originate from a single cause (one's body). When stimuli are perceived to ‘belong together,’ it is more likely that the perceptual system treats these sensory inputs as referring to the same multisensory event as opposed to separate unimodal events (Angelaki & Vatakis, 2014; Spence, 2011). In this case, the signals become partially or completely integrated, which makes it harder to discriminate conflict between the original unisensory signals. This may for example result in a reduced reliability to distinguish temporal asynchronies between signals from different senses, which can be tested empirically (Parise & Spence, 2009). However, studies investigating multisensory temporal integration in own-body context have produced conflicting findings. Hence, the influence of visual information on the temporal integration of body-related signals remains unclear. I propose two avenues for further investigation that might help bridge this gap.

One method to address the discrepancies in the literature is to use a TOJ task to test if visual body-ownership cues modulate temporal perception in a ‘normal’ population. Second, investigating visuo-tactile temporal binding in MTS could provide a unique opportunity to test multisensory theories for body-representation. In Chapters 2 and 3, I present two experiments to test whether visual information about object form and orientation modulates visuo-tactile temporal processing in non-synaesthetes and mirror-touch synaesthetes. I discuss the implications of my findings in relation to understanding body perception and MTS in Chapter 4.

1.1 Representing the body in a complex multisensory environment

The brain constantly receives signals from different sensory modalities and uses this information to create a unified representation of the world (Stein & Meredith, 1993). An important challenge for the brain in this complex multisensory environment is that it has to distinguish which unimodal signals belong to the same object or event, including one’s own body (Blanke, 2012; Ehrsson, 2012; Graziano & Botvinick, 2002; Spence, 2011). A crucial difference between perceiving our own bodies and perceiving external objects, however, is that when we perceive ourselves, we have access to unique kinds of information such as somatosensation, interoception and vestibular signals. The brain combines these sensations that emerge within the body and external sensory input to establish a sense of ‘body-ownership’, the always-present experience that ‘my body belongs to me’ (de Vignemont, 2011; Gallagher, 2000; Tsakiris, 2011). An accurate sense of body-ownership crucially relies on successful integration of multisensory information. This is evidenced by disorders where abnormal multisensory integration is linked to a distorted sense of body-ownership, such as somatoparaphrenia which results in a denial of limb-ownership (Vallar & Ronchi, 2009; Feinberg & Venneri, 2014). In the following section, I will discuss research into the underlying multisensory mechanisms for body-perception and what it has taught us about the factors important for a sense of body-ownership.

1.1.1 Investigating multisensory body-ownership cues

Body-ownership represents a fundamental aspect of body-perception (de Vignemont, 2011; Gallagher, 2000; Tsakiris, 2011). However, this sense of ownership is not restricted to one's actual body parts alone and might also extend to artificial objects, as long as these match certain properties expected of body parts (de Vignemont, 2013). This 'illusion of body-ownership' has most notably been demonstrated by the RHI, which allowed researchers to manipulate limb-ownership in an experimental setting.

In the original experiment introduced by Botvinick and Cohen (1998), each participant is seated with one arm (hidden from view by a screen) lying on a table and a realistic-looking rubber hand is placed in front. The experimenter uses brushes to stroke both the participant's own hand (out of view) and the rubber hand synchronously, while the participant observes the stroking on the rubber hand. After some time, many participants report that the felt sensation on their own hand seems to be originating from the rubber hand, which is regularly combined with a sense of ownership over the artificial hand. Afterwards the participant is blindfolded and instructed to point with the other (unstimulated) hand to the location of their own hand. Results often indicate a proprioceptive drift where the participant's estimation of the real hand is moved towards the location of the rubber hand. The RHI shows that a sense of ownership over an artificial object may result when there is a mismatch of visual, tactile and proprioceptive information and that body representations are constantly updated based on available sensory input (de Vignemont 2007; Tsakiris, Prabhu & Haggard, 2006; Tsakiris & Haggard, 2005). The RHI has provided a novel tool for scientists to manipulate the spatial, temporal and visual cues involved in body-ownership (body-ownership cues), which has tremendously increased our understanding of how multisensory information is combined to update representations of the bodily-self (Ehrsson, 2012; Kilteni et al., 2015). Much of this research has focused on the necessary and sufficient factors to establish a sense of ownership over an object which I will now review.

1.1.2 Multisensory synchrony and visual plausibility

Botvinick & Cohen (1998) initially proposed that visuo-tactile integration is both a necessary and sufficient condition to induce ownership over the rubber hand, and that the illusion indicates a tolerance to spatial discrepancies between the seen and the felt hand. They showed that the illusion was significantly reduced when the rubber hand and the participant's real hand were stroked asynchronously (see also Shimada, Fukuda & Hiraki, 2009; Tsakiris & Haggard, 2005). This highlights the importance of intermodal temporal synchrony for body-representation, which is supported by studies that show that viewing a plausible hand-shaped object without synchronous multisensory stimulation typically does not induce the illusion (e.g., Holmes, Snijders & Spence, 2006; Longo, Cardozo & Haggard, 2008, although see Martinaud, Besharati, Jenkinson & Fotopoulou, 2016). Following on from this, Armel and Ramachandran (2003) proposed a purely bottom-up account which suggests that synchronous multisensory stimulation can cause any object to be incorporated into one's body-representation. Other studies have subsequently questioned this claim by demonstrating the importance of additional cues.

Numerous studies using the RHI paradigm have demonstrated that the brain also relies on visual (structural and anatomical) information about whether the seen object is plausible for one's body to establish a sense of ownership (Costantini & Haggard, 2007; Tsakiris & Haggard, 2005; Tsakiris, Costantini & Haggard, 2008). For example, stimulation of an observed object that lacks certain hand features (such as a wooden block) does not induce the illusion of ownership (Tsakiris, Carpenter, James & Fotopoulou, 2010; Tsakiris & Haggard, 2005). This suggests that visual information about bodily-form needs to be plausible for one's own body. The posture of the observed object is also important, as studies show that an incongruent orientation with respect to the participant's body (rotated by more than 90 degrees), reduces or abolishes the illusion, despite synchronous multisensory input (Costantini & Haggard, 2007; Holle, McLatchie, Maurer & Ward, 2011; Ide, 2013; Pavani, Spence & Driver, 2000; Kalckert & Ehrsson, 2012; Ehrsson, Spence & Passingham, 2004; Lloyd, 2007; Tsakiris & Haggard, 2005).

There is some evidence for a reduction in the strength of the illusion when the viewed object is placed at a distance of more than 30cm from the observer's body (Lloyd, 2007), although this is debated (e.g., Preston, 2013; Zopf, Savage & Williams, 2010). These findings show that both synchrony of sensory inputs and the plausibility of the viewed object are important cues for body-ownership (Tsakiris & Haggard, 2005).

Based on these findings from the RHI, Kilteni et al. (2015) argue that the brain relies on information about a non-self-specific body model which contains general information about visual, structural and postural properties of the human body. We know, for example, that the body has hands and that it moves in a certain way, which helps shape this abstract model. Specialised brain regions have indeed been proposed for the visual processing of bodies, which applies to hands, bodies and anatomically plausible postures and motion (Peelen & Downing, 2007). Hence, visual cues have to satisfy certain constraints to allow for successful multisensory integration. The first step might be to establish whether the object is body-shaped or not, after which visual information can be further assessed in terms of for example texture, anatomical plausibility, spatial configuration and internal structure (Kilteni et al., 2015).

From the literature discussed in this section it is clear that body-ownership involves the perception of sensory signals, the interpretation of these signals in the context of an internal body model, and the incorporation of these signals into an online representation of the body in space (de Vignemont, 2011; Gallagher, 2000; Tsakiris, 2010; Tsakiris et al., 2006). By introducing multisensory conflicts, these studies show that multisensory synchrony and visual cues such as body-form and orientation provide important information for body-ownership. It is also evident that representations of the body are flexible and continuously updated based on new sensory information (Graziano & Botvinick, 2002; Tsakiris, 2010). However, despite the hundreds of papers currently published on the RHI, the precise interactions between body-ownership cues and how this might modulate perception in the spatial and temporal domain is still not fully understood (Makin, Holmes & Ehrsson, 2008; Tsakiris, 2010). One model that might be able to explain spatial and temporal interactions of multisensory stimuli in own-body contexts is a Bayesian integration model.

1.1.3 A Bayesian integration model for body-ownership

In multisensory perception more broadly, it is often proposed that perception of events relies on two computational mechanisms: causal inference, which determines which signals belong to one and the same object or event, and multisensory integration, which allows for the integration of unisensory signals that originate from the same source (Samad, Chung & Shams, 2015). A Bayesian causal inference model incorporates these two processes and can therefore provide a unified theory for the spatial and temporal perception of multisensory stimuli (e.g., Beierholm, Quartz & Shams, 2009; Körding, Beierholm, Quartz, Tenenbaum & Shams, 2007; Wozny, Beierholm & Shams, 2008, 2010; Wozny & Shams, 2011; Shams & Beierholm, 2005). On this view, the strength of inter-sensory coupling relies on previous knowledge that signals belong to one and the same object or event, and repeated experience that signals are statistically likely to co-occur (Bresciani, Dammeier & Ernst, 2006; Helbig & Ernst, 2007; Ernst, 2007). Signals that are strongly perceived to 'belong together' may result in a complete integration of the original signals whereas a weak binding only leads to partial integration where inter-sensory conflict may still be perceived. A strong binding between stimuli may therefore result in the reduced ability to perceive spatial and temporal discrepancies between the original unisensory signals (Parise & Spence, 2009).

A Bayesian integration model might also explain how we perceive our own bodies, because when the brain attributes an above-change probability that the signals originated from the same object (its own body), this increases the likelihood that these signals become integrated. This can therefore explain how different body-ownership cues are integrated. For example, Samad et al. (2015) propose a Bayesian integration model to explain the emergence of the RHI. In this context, the brain draws on evidence such as the spatial proximity of the real hand and the artificial hand, the temporal synchrony between visual and tactile stimulation and visual information about whether the object is plausible for one's body. When evidence from one of these factors is weak, this can be compensated for by drawing on other kinds of input (Samad et al., 2015). Visual body-ownership cues can also affect multisensory integration without induction of the RHI. This is supported by the findings from Holmes et al. (2006) who demonstrated a bias in proprioception caused by mere visual exposure to an artificial hand in a mirror, without the illusion of ownership over the hand. This shows that in this context, the brain mostly relies on visual input to establish causal inference. Hence both visual and tactile cues can independently provide information about a common source. Once a common source is determined through causal inference, this then influences *visuo-proprioceptive* integration as evidenced by a proprioceptive drift of the real hand towards the artificial hand (e.g., shown by reaching endpoint errors; Zopf, Truong, Finkbeiner, Friedman & Williams, 2011). This suggests that body-ownership cues interact within a certain context, and that this may result in the reduced ability to perceive spatial conflict between the multisensory signals. Thus, it appears that the unity assumption enhances multisensory binding in the *spatial domain*, but whether this effect in the context of one's body also extends to multisensory binding in the *temporal domain* still remains unclear as previous studies have produced conflicting results.

1.2 Body-ownership cues and changes in multisensory processing

In this section I will discuss several findings that further support the effects of the unity assumption on *spatial visuo-tactile interactions*. Building on these findings, subsequent studies have tested whether visual body-ownership cues also affect *visuo-tactile temporal binding*. However, studies have produced conflicting findings and it remains unclear whether visual body-ownership cues modulate temporal perception. I will propose several explanations for these findings and avenues to further investigate this.

1.2.1 Own-body context and visuo-tactile spatial processing

Important insight into how visual body-ownership cues can influence visuo-tactile spatial interactions comes from the crossmodal congruency paradigm (e.g., Maravita, Spence & Driver, 2003; Pavani, Spence, & Driver, 2000; Spence & Walton, 2005). Pavani et al. (2000) for example, investigate the effects of visual body-ownership cues on visuo-tactile spatial processing. They placed four tactile stimulators on the participant's own two hands (index finger and thumb) and positioned four visual distractor lights onto corresponding locations on two rubber hands. The visual and tactile stimuli could either be presented at the same location (e.g., both at the index finger) on congruent trials, or at different locations (e.g., one at the index finger and one at the thumb) on incongruent trials. Participants were asked to discriminate whether a tactile stimulus occurred on the lower (thumb) or upper (finger) position. Tactile judgements were significantly faster on congruent trials than on incongruent trials. This crossmodal congruency effect was further modulated by the orientation of the rubber hand. Results show that when the rubber hand was positioned at a plausible orientation with the participant's own hand, the crossmodal congruency effect was significantly larger than when the rubber hand was positioned at an incongruent orientation. This suggests that visual body-ownership cues such as hand orientation can affect visuo-tactile processing in the spatial domain.

Although visual information plausible for one's body seems to influence the crossmodal congruency effect, there is also evidence that spatial multisensory processing can be influenced by visual information that is not highly realistic for one's body. Studies show that observing visual stimuli near one's body through a video monitor (Tipper, Phillips, Dancer, Lloyd, Howard & McGlone, 2001) or even observing the shadow of one's hand (Pavani & Castiello, 2004) can influence visuo-tactile spatial interactions. Building on this, one study (Igarashi, Kitagawa & Ichihara, 2004) investigated whether visual information presented on a two-dimensional plane (a simple drawing of a hand) can influence visuo-tactile spatial interactions on a crossmodal congruency task. On each trial, a participant felt a tactile stimulus presented either at the tip or the base of the forefinger and observed a line drawing of a hand with visual distractor stimuli at corresponding locations to the stimuli on the participant's own hand. When the visual distracter stimuli and tactile stimuli were presented at incongruent locations (e.g., at the tip visually and the base of the forefinger for the tactile stimulus), tactile discrimination performance was slower and less accurate as opposed to when visual and tactile targets were spatially congruent. These crossmodal congruency effects were further modulated by visual orientation cues, as viewing the picture of the hand in a plausible orientation with one's own body resulted in stronger effects than when the picture was rotated at an implausible angle. This implies that even a simple two-dimensional line drawing of a hand provides important visual information about orientation, which modulates processes involved in maintaining an internal body representation.

Here I reviewed literature showing that visual plausibility is important for spatial interactions between visual and tactile stimuli. A clear outstanding question is whether visual plausibility also affects temporal interactions of multisensory information.

1.2.2 Own-body context and visuo-tactile temporal processing

Recently researchers have started to investigate whether visual body-ownership cues also affect the way we perceive multisensory stimuli in the temporal domain. Shimada et al. (2009) showed that participants still reliably experienced the RHI even when the visual stimulation on the rubber hand and tactile stimulation on the participant's own hand were presented with a 300ms delay. The range in which participants can still reliably distinguish temporal delays can be as low as 20 - 80ms for simple visual and tactile stimuli (e.g., flashes and vibrations; Fujisaki & Nishida, 2009; Harrar & Harris 2008; Hirsh & Sherrick, 1961; Spence, Baddeley, Zampini, James & Shore, 2003). One explanation for the finding by Shimada et al. (2009) is that increasingly complex stimuli results in diminished sensitivity for temporal delays (Vatakis & Spence, 2006; Vroomen & Keetels, 2010). Alternatively, it is possible that the visual presentation of a hand affect one's sensitivity to multisensory temporal asynchronies. This might suggests that the observed effects from visual information on visuo-tactile interactions in the spatial domain also extend to the temporal domain.

Building upon these findings, Ide and Hidaka (2013) employed a TOJ task to test whether the presentation of a simple hand image affects perceptual temporal sensitivity. In a TOJ task, participants judge the temporal order of stimuli from different sensory modalities which are presented at varying stimulus onset asynchronies (SOAs). Performance is measured as the smallest interval at which participants can still reliably distinguish the temporal order of the crossmodal stimuli (the 'just-noticeable difference' JND). The study by Ide and Hidaka (2013) compared three conditions in which visual plausibility was manipulated (black line drawings of a forward hand, an inverted hand and an arrow). A light flash was presented on the index finger of the line drawing of a hand and a vibration was applied to the tip of a participant's left index finger. The participant judged whether the visual light flash or the tactile stimulus on his or her own hand was presented first. The results indicate that a plausible hand image (forward hand) compared to an implausible image (inverted hand and arrow) decreased participants' ability to establish the temporal order of stimuli as indicated by larger JNDs. To rule out the possibility that the effects were due exclusively to higher attentional capture effects for the forward hand image, their second experiment tested whether the TOJ between auditory and visual stimuli differed among these images. The results confirmed that this was not the case. Based on these findings the authors suggest that a plausible hand image may enhance the internal proximity between the visual and tactile stimulus, resulting in decreased temporal perceptual discrimination.

Converging evidence comes from a study that looked at the effect of body-ownership cues on the temporal aspect of multisensory information in a virtual reality set-up (Maselli, Kilteni, López-Moliner & Slater, 2016). In two experiments they tested whether a plausible visual cue on a virtual body and a corresponding tactile cue on the participant's real body would expand the temporal window of integration (indicated by a larger JND) for these stimuli and whether this is affected by the body-ownership illusion itself. Participants wore a head-tracked head-mounted display which streamed a digital 3D replica of the room. By looking down participants could see a gender-matched virtual body which coincided with the location of their real body. This virtual set-up is known to be sufficient for inducing a body-ownership illusion over the virtual body due to congruent visuo-proprioceptive cues (Maselli & Slater, 2013, 2014). Experiment 1 included two conditions: one in which a rotating geared-wheel was touching a virtual finger and one in which the wheel remained separated from the virtual finger by 6mm. At various SOAs a tactile stimulus was applied to the participant's real fingertip. Participants rested their arms on a table and had to determine the temporal order of a visual stimulus (one full rotation of a virtual geared-wheel (50ms duration) and a tactile stimulus (50ms vibration). As predicted, results indicated larger JNDs for the touch conditions which can be explained by information regarding a common origin of the visual and tactile stimuli when participants see the finger being touched by the moving geared-wheel while receiving tactile feedback. Experiment 2 tested whether the virtual body-ownership illusion mediated causal binding. Participants performed a TOJ in two conditions, one with the same set-up as Experiment 1 and one where the virtual arms of the virtual body were replaced by wooden sticks to inhibit the ownership-illusion (studies show that virtual body-ownership illusions require a humanoid shape; e.g., Petkova & Ehrsson, 2008). Results from Experiment 2 support the hypothesis that the effect of causal binding on the temporal integration of visual and tactile stimuli as observed in Experiment 1 was mediated by a sense of ownership over the virtual body. The findings from both experiments demonstrate that multisensory integration supports the body-ownership illusion, which in turn modulates subsequent multisensory temporal processing (Maselli et al., 2016).

These studies (Ide & Hidaka, 2013; Maselli et al., 2016; Shimada et al., 2009) suggest that visual information about one's body modulates visuo-tactile interactions not only in the spatial domain but also in the temporal domain. This supports a Bayesian integration model for body-ownership, as it appears that in these studies, the brain attributes an above-chance probability that the multisensory signals originate from a common source (its own body), and hence multisensory signals are more likely integrated/bound, even when these are spatially or temporally somewhat discrepant.

Contrary to these findings, Keys and colleagues (2018) investigated the effect of visual body-ownership cues on visuo-tactile temporal perception with a two-interval forced-choice task, and found evidence for the null hypothesis that there is no effect (Keys, Rich & Zopf, 2018). In Experiment 1, each participant was asked to indicate perceived asynchronies between visual stimuli (visual flashes presented next to an anatomically plausible or implausible rotated model hand) and tactile stimuli (vibrotactile stimulation on the participant's hidden hand). In Experiment 2, the strength of multisensory bodily-self cues was increased via induction of the RHI. Results shows that in both experiments, viewed hand orientation did not influence visuo-tactile asynchrony detection, supported by Bayes analyses to estimate the strength of evidence for the null result.

The null result reported by Keys et al. (2018) is not in line with previous visuo-tactile TOJ findings, a discrepancy which may be attributed to several factors. First, the studies by Ide and Hidaka (2013) and Maselli et al. (2016) used a TOJ task whereas Keys et al. (2018) used a stimuli asynchrony detection task, which may have picked up on different cognitive mechanisms (Love, Petrini, Cheng & Pollick, 2013). Second, the visual stimuli in these studies differed considerably in terms of ecological validity. The study by Maselli et al. (2016) paired a visual stimulus (rotating geared-wheel touching the participant's virtual finger) with a corresponding tactile stimulus (a vibration on the participant's real finger). In this set up, it seems quite realistic that the felt touch originated from the observed touch. The other two studies used much less realistic visuo-tactile stimuli-pairings such as a light presented next to a line-drawing of a hand (Ide & Hidaka, 2013) or a plaster hand (Keys et al., 2018), paired with a tactile vibration on the participant's own hand. In context of a Bayesian integration model, it seems plausible that the ecological validity of the visual and tactile stimuli in these studies affects the degree of temporal binding. Highly realistic stimuli provide more reliable information about whether the information originated from the same source and hence whether these should be bound more strongly into a unified multisensory percept. This could potentially explain why Maselli et al. (2016) found an effect whereas Keys et al. (2016) did not. However, this still does not account for the findings by Ide and Hidaka (2013) as these did not use very realistic visuo-tactile stimuli pairings either. Hence, a third reason for the discrepancy in findings might be that Ide and Hidaka (2013) and Maselli et al. (2016) used relatively small samples (12 and 14 participants respectively) whereas the study by Keys et al. (2018) included a markedly larger sample (30 participants). Small sample sizes and low-statistical power can increase false positive rates, and hence we cannot rule out that previous findings could be due to small samples (Button, Ioannidis, Mokrysz, Nosek, Flint, Robinson & Munafò, 2013). To bridge these gaps, it would be informative to test the effect of visual body-ownership cues on visuo-tactile temporal perception: 1) with a TOJ task, 2) highly realistic visuo-tactile stimuli pairings 3) and a large sample. This will provide insight into whether stimuli that are perceived to 'belong together' (the unity assumption) in own body-contexts, become integrated more strongly in the temporal domain.

Learning more about whether visual body-ownership cues modulate visuo-tactile temporal binding might also help explain findings from studies that have shown that visual cues plausible for one's body actually *enhanced* visuo-proprioceptive temporal perception, which is contrary to the findings from visuo-tactile studies which show *decreased* temporal perception. A study by Hoover and Harris (2012) for example, tested whether plausible cues signaling one's own body influenced detection of delays between visual and proprioceptive stimuli. They presented participants with videos of their own finger movements, either from an egocentric (self) or allocentric (other) perspective. By introducing small delays between the actual movement and visual feedback they investigated whether visual cues that matched internal representations enhanced participants' temporal perception on a two-interval force-choice task. The results indicate that viewing a hand in an egocentric position versus an allocentric position leads to greater sensitivity to detect small temporal delays. These temporal sensitivity effects were also found in a follow-up study that looked at the effects of viewing delayed self-generated head and hand movements through a mirror (Hoover & Harris, 2015). In another study, Zopf et al. (2015) used a 3D virtual reality set-up and looked at the effects of visual form and orientation cues on visuo-proprioceptive temporal perception and reported similar findings.

As visual, tactile and proprioceptive information needs to be integrated to accurately perceive one's body, a Bayesian integration model might predict that visual body-ownership cues should enhance temporal binding of *visuo-tactile* and *visuo-proprioceptive* stimuli. The findings from visuo-proprioceptive studies combined with the null findings by Keys et al. (2018), might suggest that the unity assumption influences multisensory processing in many aspects but not in terms of temporal integration, at least not in own-body contexts. If it does turn out that visual body-ownership cues only affect visuo-tactile but not visuo-proprioceptive temporal binding, this might indicate different underlying mechanisms for integration, which future studies could further investigate.

1.3 Visuo-tactile temporal binding in mirror-touch synaesthesia

So far I have discussed how body-ownership cues might affect temporal binding in the 'normal' population and how this could be explained by a Bayesian integration model for body-ownership. A unique opportunity to test this theory is by looking at a population where vision-touch interactions are unusual. Individuals with MTS for example, experience a touch sensation on their own bodies when they observe someone else being touched (Banissy, Kadosh, Maus, Walsh & Ward, 2009). It is possible that in MTS, visual information in relation to touch modulates integration of multisensory information differently (e.g., Davies et al., 2013). I will now discuss a theory for the underlying causes of synaesthesia, and how this also might extend to MTS.

1.3.1 The continuum hypothesis and crossmodal associations

Synaesthesia is a condition where an ordinary stimulus involuntarily results in an additional conscious experience (Grossenbacher & Lovelace, 2001). The underlying mechanisms for synaesthesia remain unknown, and it is currently debated whether it represents a truly distinct perceptual phenomenon, or if it instead relies on common processes for multisensory integration The latter possibility is often referred to as the 'continuum hypothesis' which proposes a common mechanism for crossmodal associations in both non-synaesthetes and synaesthetes, which is simply exaggerated in the second group (Newell & Mitchell, 2016; Simner, 2012; Ward et al., 2006 although see Deroy & Spence, 2013, 2016) In line with this, Martino and Marks (2001) suggested that (canonical) 'strong synaesthesia' lies on the extreme end of a spectrum of otherwise normal perceptual experiences, whereas 'weak synaesthesia' lies somewhere in the middle and reflects normal crossmodal associations which are universally shared.

Numerous studies indeed suggest that crossmodal associations can influence behaviour in non-synaesthetes (for a review see Spence, 2011). These studies often involve a speeded classification task where participants are asked to classify stimuli in one sensory modality while ignoring task-irrelevant stimuli in another modality (Marks, 2004). Results typically demonstrate that participants respond faster and more accurately when the relevant and irrelevant stimuli in the different modalities are matched as opposed to mismatched. However, it is unclear whether these findings genuinely point to perceptual similarity between the stimuli. Proctor and Cho (2006) for example, argue that difference in performance on these speeded classification tasks, may be attributed to structural similarity, such that stimulus and response alternatives are coded as positive and negative polarity along different dimensions. Stimuli and response alternatives that activate opposite ends of a polarity spectrum (a conflict in polarity codes) result in a slower response-selection process. This polarity correspondence might be sufficient to produce the observed crossmodal mapping effects (Proctor & Cho, 2006). Contrary to this 'polarity-correspondence principle' however, one study showed that crossmodal associations between pitch and spatial location modulated attentional orientating and hence that this pitch-induced cuing effect cannot simply be explained by a bias to assign polar opposites to any binary stimulus (Chiou & Rich, 2012). Additional studies are needed to clarify whether these observed effects from crossmodal associations on behavioural tasks reflect perceptual similarities between stimuli or whether these should be attributed to other factors such as response biases. Because of this, it remains unclear whether these crossmodal associations occur between all sensory modalities and, more importantly, whether these are universally shared by all people.

More direct evidence comes from one study by Parise and Spence (2009), which demonstrated that crossmodal associations actually enhanced visuo-tactile temporal integration on a TOJ task in non-synaesthetes. Participants made unspeeded TOJs about whether the visual or auditory stimulus was presented second. The visual stimuli in the first experiment consisted of a small and large circle and the auditory stimuli consisted of a high-pitch and a low-pitch tone.

On each trial, the visual and auditory stimuli were either congruent (e.g., a small circle matched with a low-pitched tone or a large circle matched with a high-pitched tone) or incongruent (e.g., a small circle matched with a high-pitched tone). The results indicate that participants' ability to discriminate the temporal order of audio-visual stimuli was significantly reduced for the congruent pairs relative to incongruent pairs. Parise and Spence (2009) explain these findings in light of a Bayesian integration model, where crossmodal associations can be understood as a coupling prior that modulates the strength of integration. If the perceptual system indeed relies on crossmodal associations to integrate stimuli across different senses, we would expect stronger coupling for congruent than for incongruent pairs. As a result, participants' estimates about the temporal order of crossmodal stimuli should be less reliable in the congruent situation, as this requires access to inter-sensory temporal conflicts. Hence the reported findings in this study support the idea that congruent crossmodal associations enhance temporal integration in non-synaesthetes. Further, studies suggest that the unity assumption could also enhance temporal binding for realistic speech stimuli (e.g., Vatakis & Spence, 2007), however, others have not been able to find these effects for non-speech audio-visual stimuli (Vatakis, Ghazanfar & Spence, 2008; Vatakis & Spence, 2008). Hence, additional evidence to support the findings by Parise and Spence (2009) is currently lacking, and it remains to be clarified whether crossmodal associations actually *enhance multisensory integration* and if this extends to all sensory modalities.

Despite a lack of direct evidence to support the effects of crossmodal associations on multisensory integration, the continuum hypothesis is becoming increasingly popular due to numerous studies that show that experiences had by synaesthetes at least resemble the crossmodal associations made by most people (e.g., Beeli, Esslen & Jäncke, 2007; Chiou, Stelter & Rich, 2013, Cohen Kadosh, Cohen Kadosh & Henik, 2007; Hubbard, 1996; Marks, 1974, 1987; Rich, Bradshaw & Mattingley, 2005; Ward, Huckstep & Tsakanikos, 2006; Sagiv, Simner, Collins, Butterworth & Ward, 2006; Simner, Ward, Lanz, Jansari, Noonan, Glover & Oakley, 2005). For example both music-colour synaesthetes and non-synaesthetes pair high-pitch sounds with light and bright colours, with the main difference being that synaesthetes experience these colours on a conscious level while for non-synaesthetes these are mere associations (Chiou et al., 2013; Ward et al., 2006). Another example comes from a study that compared the associations made by grapheme-colour synaesthetes and non-synaesthetes (Rich et al., 2005). Results demonstrated clear overlap in letter-colour combinations experienced by synaesthetes, for example for 47% of synaesthetes the letter D elicited brown and for 45% the letter Y elicited yellow. Out of the 13 significant commonalities reported for this group, 11 were also apparent in the non-synaesthete group who were asked to associate letters with colours. In sum, these studies suggest that synaesthetic experiences do resemble the crossmodal modal associations made by non-synaesthetes in many aspects, but whether this shows that synaesthesia is a mere exaggeration of normal perceptual mechanisms is still not clear (Deroy & Spence, 2013, 2016). First because it is ambiguous whether crossmodal associations are universally shared due to methodological limitations and potential confounding factors such as response biases. And second, evidence to support the claim that crossmodal associations actually enhance multisensory integration in non-synaesthetes is still lacking. Hence, the current evidence does not convincingly show that synaesthetic experiences and crossmodal associations lie on a continuum.

One potential way to test the continuum hypothesis is by directly comparing results from non-synaesthetes and synaesthetes on a TOJ task. If synaesthesia indeed relies on common perceptual mechanisms that are simply exaggerated in synaesthetes, we might expect to find stronger crossmodal integration and hence temporal binding as evidenced by larger JNDs for this group. In the next section I propose how we might investigate this in MTS.

1.3.2 Mirror-touch synaesthesia: Threshold Theory and Self-Other Theory

The idea that synaesthesia relies on common perceptual mechanisms might also extend to MTS. Ward & Banissy (2015, 2017) provide two models that may explain the underlying mechanisms for this condition. The first is termed Threshold Theory, which proposes that MTS reflects an extreme end-point of an otherwise normal mirror-system for touch. Falling on this extreme end-point means that the level of activity in the somatosensory system crosses a certain threshold for awareness, leading to a conscious experience of touch. In non-synaesthetes this threshold is never crossed, resulting merely in an implicit vicarious response.

Some evidence for the Threshold Theory comes from functional Magnetic Resonance Imaging (fMRI) studies which found that MTS show hyper-activity in both primary (SI) and secondary (SII) somatosensory cortex when observing touch a human body but not to an object (for a review, see Keysers, Kaas, & Gazzola, 2010). However, these are mostly single-case studies and further evidence is required to establish whether these findings extend to all individuals with MTS. In addition, studies have attempted to induce MTS symptoms in non-synaesthetes (Bolognini, Miniussi et al., 2013; Bolognini, Rossetti et al., 2014). One study applied transcranial Direct Current Stimulation (tDCS) over SI to increase cortical excitability and raise neural activity above the threshold for perceptual awareness (Bolognini et al., 2013). Non-synaesthete participants performed a vision-touch interference tasks, which is commonly used to establish MTS. In this task, participants receive a tactile stimulus while at the same time viewing touch to a body part or an object. They are asked to report the location of the felt touch while ignoring the viewed touch. When the viewed and felt touch are spatially incongruent compared to congruent trials, MTS are typically slower and less accurate at establishing which side of their body was touched. This suggests that the viewed touch results in a conscious experience of touch on the synaesthete's own body. This effect is specific for touch to a human and does generally not extend to objects. This crossmodal interference effect is typically not observed in individuals without MTS (Banissy & Ward, 2007). However, after applying tDCS stimulation (as opposed to sham stimulation) targeted at SI, non-synaesthete participants showed a similar vision-touch interference effect only when observing touch to a human body part and not an object. The degree of interference was furthermore correlated with self-reports of symptoms resembling MTS. These findings might suggest that MTS relies on a hyperactive mirror-system for touch (and only when observing touch to humans), but one should be mindful when interpreting these results due to technical limitations of tDCS. Stimulation is applied with relatively large electrodes (20-35 cm) which makes the technique not very focal (Miniussi et al., 2008). This is supported by findings from (fMRI) studies that have demonstrated that tDCS affects activity across a large area of the cortex (Saiote et al., 2013). Researchers should thus be cautious when attributing the observed effects to a specific area of the cortex based on results from tDCS alone (Filmer et al, 2014). In sum, there is some preliminary evidence for the Threshold Theory but further studies are needed for more reliable interpretations.

By contrast, the Self-Other Theory proposes that MTS arises due to a failure to correctly distinguish self from others. Evidence to support this comes from studies that have found that MTS exhibit different behaviours compared to non-synaesthetes when it comes to body-ownership and agency (Cioffi, Banissy, & Moore, 2016), control of imitation (Santiesteban, Bird, Tew, Cioffi, & Banissy, 2015) and perspective taking (Derbyshire, Osborn, & Brown, 2013). The main difference between the Threshold Theory and the Self-Other Theory is that for the first, the cause for MTS lies within the mirror-system for touch, whereas the latter attributes the cause to a different brain network which is involved in controlling self-other perspectives.

The Threshold Theory resembles the continuum hypothesis in some important aspects. In relation to MTS, both might suggest that (otherwise normal) visuo-tactile associations lie on a spectrum and that only when a certain threshold is reached does this result in a conscious mirror-touch experience (although for a different explanation, see Banissy & Ward, 2015, 2017). Crossmodal associations can be understood as *a priori* mappings between different sensory inputs which may result in behavioural congruency effects (Spence, 2011). If MTS indeed relies on a hyper-active mirror-system for touch, we might predict that the mappings between visual and tactile stimuli in body contexts are much stronger in these individuals, due to higher expectations that these visual and tactile inputs co-occur. The findings by Ide and Hidaka (2013) suggest that visual body-ownership cues alone, without the induction of body-ownership (unlike Maselli et al., 2016), enhanced the unity assumption which resulted in decreased sensitivity to visuo-tactile temporal conflict in non-synaesthetes. Based on the Threshold Theory, I predict that visuo-tactile temporal binding effects on a TOJ task will be stronger for MTS than for non-synaesthetes when comparing touch to a human hand versus an object. In addition, the Self-Other theory suggests that MTS might also have difficulty distinguishing self from others, and in line with this I predict that hand orientation will have less of an effect on visuo-tactile temporal binding in the MTS sample compared to the non-synaesthete sample.

1.4 Interim summary: body-ownership cues and temporal perception

To accurately perceive oneself, the brain has to establish which unimodal signals originated from its own body and should therefore be integrated (Graziano & Botvinick, 2002; Spence, 2011; Stein & Meredith, 1993). Body-ownership represents a fundamental aspect of body perception and studies incorporating the RHI have provided valuable insight into the spatiotemporal and visual cues that modulate multisensory integration (Makin et al., 2008). A Bayesian integration model might explain how these body-ownership cues interact and how this can affect temporal and spatial multisensory perception. However, due to conflicting research findings, it remains unclear whether effects of the unity assumption also extend to temporal integration. Several studies suggest that visual body-ownership cues enhance visuo-tactile temporal binding (Ide & Hidaka, 2013; Maselli et al., 2016; Shimada et al., 2009), whereas others have failed to observe such an effect (Keys, Rich & Zopf, 2018). There are several factors that might account for this discrepancy in findings, such as task differences, varying ecological validity of the visuo-tactile stimuli pairings, and small sample sizes in two of the studies. To distinguish these alternatives, we need to test the effects of visual body-ownership cues on visuo-tactile temporal processing with a TOJ task, highly realistic stimuli and a sufficiently large sample.

In addition, theories about the underlying mechanisms for MTS suggest that this condition might be linked with stronger crossmodal associations between visual and tactile stimuli in context of human touch. Following this, I hypothesise that visuo-tactile temporal binding effects would be stronger for MTS than for non-synaesthetes when comparing touch to a human hand compared to an object, as indicated by larger JNDs on a TOJ task. In addition, I predict that the effects of hand orientation will be less strong in the MTS sample. This exploratory research might indicate novel avenues for future studies into temporal perception.

1.5 Research questions

Body-ownership cues modulate multisensory processing, but it remains unclear whether visual information also alters temporal perception of visual and tactile stimuli. In this thesis I investigate the influence of visual body-ownership cues on TOJs in two experiments. The first experiment involves non-synaesthetes, and I predict that for this group, plausible visual cues about object form and orientation will enhance visuo-tactile temporal integration. The second experiment involves individuals with MTS and I predict that in these individuals, plausible visual cues about form (but not orientation) will result in even stronger temporal binding. I address the following research questions:

1) Do visual body-ownership cues (form, orientation) affect visuo-tactile temporal order judgements in non-synaesthetes?
2) Are visuo-tactile temporal binding effects due to form (but not orientation) larger in mirror-touch synaesthetes compared to non-synaesthetes?

In this chapter I presented a Bayesian integration model which might explain multisensory processing in context of one's body. I presented a number of open questions about the effects of body-ownership cues on the temporal processing of visual and tactile cues. I also discussed possible causes for synaesthesia and MTS in particular. Testing these individuals might provide novel insights into both abnormal and normal multisensory perception. In the following chapters, I present two experiments in which I test whether visual body-ownership cues modulate visuo-tactile temporal perception.

Chapter 2: The effect of viewing touch to a hand on visuo-tactile temporal order judgements in non-synaesthetes (Experiment 1)

The aim of the first experiment was to investigate whether observing touch to a human hand modulates the temporal perception of visual and tactile stimuli in non-synaesthetes. Each participant was seated in front of a computer and watched videos depicting touch to either an egocentric (self-specifying) hand, an allocentric hand (other-specifying, rotated by 180 degrees) or a sponge, selected as a control object. On each trial a tapper applied a soft tap to the participant's own hand with varying SOAs relative to the visual touch. The task was to determine whether the seen or felt touch came first. For each condition I calculated the smallest interval for which participants could reliably discriminate the temporal order of the visual and tactile touch stimuli (JND). I conducted a Bayesian analysis comparing the three conditions to test whether visual cues in terms of form and orientation modulate visuo-tactile temporal perception.

2.1 Method

2.1.1 Preregistration

It is important for the credibility of research to establish and commit to a method for data analysis before looking at the actual data (Ioannidis, 2005). Preregistration of a study allows readers and reviewers to gauge to which extent this has been done. This is the only situation in which common statistical tests are applicable and where results may be understood as confirmatory as opposed to being exploratory (Wagenmakers, Wetzels, Borsboom, van der Maas & Kievit, 2012). In line with this approach, I preregistered the methods and planned analysis for Experiment 1 on the Open Science Framework (OSF) which can be found in Appendix A or accessed online[1].

[1] www.osf.io/4dzrg/?view_only=70b8adadf3ac40bba43857fe595bbbd8

2.1.2 Determination of sample size and stopping rule

I used a Bayesian analysis which allows one to monitor the data as these accumulate and data collection can be stopped at any time (Rouder, 2014). I planned to collect data from an initial 15 participants before calculating the Bayes factor to check if the data were sensitive enough to favour one hypothesis over another. My initial sample size is based on previous studies that found significant effects with between 10 and 12 participants (Ide & Hidaka, 2013; Hoover & Harris, 2012, 2015; Zopf et al., 2015). I planned to monitor the Bayes factor as data were collected and to end the experiment whenever it reached a Bayes factor of 10, indicating 'strong evidence' (Jeffreys, 1998; Rouder, Speckman, Sun, Morey & Iverson, 2009). If the Bayes factor had not reached 10 by October 2018, I planned to stop data collection due to time constraints for submitting this thesis.

2.1.3 Participants

Due to time restrictions I finished testing before reaching a Bayes factor of 10 and ended up with a total of 41 right-handed individuals with normal or corrected-to-normal vision for Experiment 1 (mean age = 26 years, SD = 9 years, 27 female). Participants provided written consent and received $15 per hour for participation. The Macquarie University Human Research Ethics committee approved the study before commencement of data collection (see Appendix D for ethics approval).

2.1.4 Stimuli and apparatus

For the TOJ task I used visual stimuli consisting of three videos depicting touch to either a human hand in an egocentric orientation, the same hand but in an allocentric orientation or an object. The videos were displayed on a computer screen. The tactile stimulus was applied by a tapper to the participant's right hand. Afterward the TOJ task participants also filled out three questionnaires on a computer.

Experimental set up. Each participant was seated at a desk in front of a computer screen and placed their chin on a chin-rest. The distance between the participant's eyes and the computer screen was 18.3cm. Before the start of the experiment, a tactile stimulator was attached to the back of the participant's right hand, just below the junction between the hand and the middle finger (the metacarpophalangeal joint). A printed screenshot of the hand video was initially placed next to the participant's right hand to match the relative location of the tactor as closely as possible to the relative location of observed touch on the screen. The participant's right hand was then placed in front on the table and aligned with the middle of the computer screen at a distance of 4.3cm from the screen. The screen was placed 6.7cm up from the table, which resulted in a vertical distance of 8.7cm between the participant's own hand and the hand on the screen. The participant's hand was furthermore hidden from view with a black piece of fabric (see Figure 1 for a depiction of the experimental setup). Participants responded by pressing a blue (H) or yellow (J) key on a keyboard which was placed 3.5 cm to the left of the middle of the computer screen.

Figure 1. Experimental set up. Participants watch videos of an object being touched and indicated whether the seen touch or the felt touch came first by pressing one of two response keys with their left hand. To mask any noise from the tactor, participants listened to white noise via headphones. Viewing distance was constrained with a chin rest.

Visual stimuli. The visual stimuli consisted of videos depicting touch to a) a human hand in an egocentric view, b) a human hand in an allocentric view and c) to a sponge (see Figure 2). All videos were exactly four seconds long. These can be found on the OSF site for this project.

A. B. C.

Figure 2. Screenshots of the videos depicting touch to either a human hand in an egocentric view (A), a human hand in an allocentric view (B) or a sponge (C).

It was crucial that that the timing, movement and location of the touch was exactly identical in all three videos to eliminate any confounding factors. Further, a TOJ task measures performance in milliseconds which means that a slight temporal difference between experimental stimuli can drastically influence the results. To control for the exact movement and timing of touch I used DaVinci Resolve video editing software to edit the final videos. First, I filmed two videos, one of a stationary hand and one of a stationary sponge. The reason to use actual video footage over a static image was to increase visual realism, for example, due to very small jitter and blood flow in the hand. The sponge was matched with the hand in all aspects (size, light, shade, colour and white balance) so that it differed only in form. I used a sponge for the control condition as it depresses to touch in the same way as the hand. To create a realistic touch event, where the surface was slightly indented upon touch with realistic shadows, I filmed the black stick touching a green patch (16mm in diameter) placed on a soft material. This meant that after editing it actually looked as if the hand and the sponge were being touched.

Another benefit of showing an indentation is that the exact moment of touch stands out more prominently during the TOJ task. This recreation of real touch could only be achieved by filming the stick touching a coloured surface so that it could later on be etched and separated from the background with the shadows intact. I changed the colour of the patch to be white afterwards in the editing software, so that it would visually stand out less (I could not get rid of it entirely). I then overlaid the edited touch video showing a hand coming into the screen and touching a white dot with a stick, onto the video of the stationary hand and sponge. I created a video depicting an allocentric hand by flipping the video of the egocentric hand. Again I overlaid the touch video with the hand and stick coming in so that the exact timing and location of the hand coming in to the screen was kept identical. I cut each video up into 120 separate frames in MATLAB. This editing process was crucial to the experiment as it allowed me to control the onset and presentation of the video frames relative to the touch across the three conditions.

Tactile stimulus. The tactile stimulus was a 30ms pulse of the vibrotactile stimulator, which applied a tap to the back of the participant's hand. The touch stimulus closely matched the visual touch from the stick in the videos in terms of phenomenology and duration.

Computers and hardware. Videos were presented on a ASUS monitor. The tactile stimulus was applied via an electromagnetic solenoid-type Dancer Design[2] tactor vibrotactile stimulator (diameter: 18 mm and probe height: 12 mm) and an amplifier (Dancer Design TactAmp 4.2 with a D25 serial port). I presented and controlled stimulus presentation via MATLAB, using the Psychophysics Toolbox extension Psychtoolbox-3 (Brainard, 1997; Pelli, 1997; Kleiner, Brainard, Pelli, Ingling, Murray & Broussard, 2007). To mask any noise from the tactor, participants listened to white noise via an around the ear, closed-back headphones (Sennheiser HD 280 pro, 64 ohm).

Questionnaires. To assess MTS I used a screener adapted from Ward, Schnakenberg and Banissy (2018). This consisted of 20 short video clips depicting touch to a human or an inanimate object and four videos of someone scratching their chest or upper arm. After each video participants were asked (via multiple choice options) whether they experienced anything on their body, how they would describe the sensation and where on their body it was felt. To test for other types of synaesthesia I used a short-synaesthesia questionnaire which included questions related to the most common types of this condition and asked participants to indicate whether they usually experience any additional perceptual experience for a list of certain sensory inputs. To assess three factors of empathy (cognitive empathy, social skills and emotional reactivity) I employed a short empathy questionnaire with three five-item scales (Muncer & Ling, 2006). Some research suggests that MTS might be an extreme form of normal empathy (Banissy & Ward, 2007; Ward

[2] www.dancerdesign.co.uk

et al,. 2018). Hence I wanted to explore whether in non-synaesthetes, stronger temporal binding for the hand conditions (as evidenced by large JNDs) would also be correlated with higher empathy scores. The synaesthesia and empathy questionnaires can be found in Appendix B.

2.1.5 Design and procedure

Each participant performed a standard visuo-tactile TOJ task. During each trial the participant watched one of the three videos depicting touch and felt a touch on the back his or her own hand with varying SOAs to the visual touch. The task was to determine whether the visual touch on the screen or the felt touch on one's own hand came first. During the experiment a participant did not receive feedback on performance. Before starting the task, each participant was asked to remove any jewellery from the right hand.

In a repeated-measures design, I manipulated the following three independent variables: (1) the object being touched (egocentric hand, allocentric hand, sponge), (2) the temporal gap between the visual and tactile stimulus (stimulus onset asynchronies, ± 33, ± 67, ± 100, ± 133, ± 167 ± 200 ± 333ms), (3) the order of presented stimuli (visual touch first, tactile touch first).

For each of the three conditions there were 20 trials with 14 different SOAs resulting in 840 trials in total per testing session. The order of these trials was randomised. Half of these trials included a visual-leading stimulus and half a tactile-leading stimulus. There were scheduled breaks and a participant could choose to take a break or continue the experiment by pressing the space bar.

Each participant was asked to respond with the left hand to indicate whether the seen touch on the screen or the felt touch on one's own hand came first. A yellow and blue sticker (corresponding to either 'visual-first' or 'tactile-first') were placed over the J and H response keys and these were counterbalanced across participants to eliminate the effect of any response bias. This meant that half the participants responded to the 'visual-first' cue with their index finger and to the 'tactile-first' cue with their middle finger and for the other half of participants this was the other way around. A note describing the response options was placed next to the response keys as a reminder for the participant. Participants were encouraged to take sufficient time when responding. Inter-trial timing was jittered to reduce the likelihood of participants getting into a routine response. The next trial started 800~1200ms after a response was recorded.

To keep participants focused and reduce expectancy effects, I slightly changed the exact moment at which the visual touch happened in each video. I used MATLAB to cut each of the three videos into 120 individual frames (each frame with a duration of 33.33ms). The first six and the last six frames of each video depicted a stationary hand or object (before and after the hand with stick has come in for the touch). This allowed variance of up to six frames at either the start or end of the video while keeping each video the same 120 frames. The start frame of each video was randomly varied on each trial so that the seen touch on the screen always occurred at slightly different times.

Prior to the experiment, participants performed a short practice run to familiarise with the task and practise the button responses. For the practice run the participants completed trials for all three conditions with all SOAs presented twice per condition.

The practice run and experiment combined took approximately one hour to complete. This was followed by three questionnaires which took another 20 minutes to fill out.

2.1.6 Data analysis

I compared the group mean JND between the key experimental conditions. To calculate a participant's individual JNDs, I first calculated the proportion of 'tactile-first' responses for each SOA in each condition. For a given SOA and condition, 1 = 100% 'tactile-first'/0% 'visual-first' responses, and 0 = 0%'tactile-first'/100% 'visual-first' responses. For each individual, I fitted the sigmoid functions (cumulative Gaussian distributions) to the proportion of 'tactile-first' responses and modelled the TOJ response data for each of the three conditions using maximum likelihood estimation. The above was done in MATLAB by utilising the Palamedes toolbox (Prinz & Kingdom, 2009). I then calculated each participant's just-noticeable difference (JND) (one for each of the three conditions) from the fitted psychometric functions, using the formula: JND = (75% threshold - 25% threshold)/2. Finally, I calculated each participant's Point of Subjective Simultaneity (PSS) to establish any bias towards the visual or tactile stimulus. The PSS is the SOA at the 50% crossover point (the same number of 'visual first' and 'tactile first' responses), which means that participants were maximally unsure about the temporal order of the visual and tactile stimuli (Vroomen & Keetels, 2010). The PSS is reported for completeness but does not provide relevant information about the strength of coupling between the visual and tactile stimuli (Parise & Spence, 2009).

Data exclusion. First, I excluded participants with a JND larger than three standard deviations from the group mean in any condition as these were considered outliers. Second, if any of the three curves (representing the three conditions) for the remaining participants failed to converge on a solution for a sigmoid function for a given condition, all data for that participant was excluded from further analysis. Incomplete datasets due to a technical error or a failure to perform the task were also excluded.

Bayesian analysis. One of my motivating factors to use a Bayesian analysis is that it allows us to make inferences for one of three scenarios: 1) for the alternative hypothesis (H1) and against the null hypothesis (H0), 2) for H0 and against H1, and 3) that there is insufficient evidence to support either hypothesis. Frequentists analyses calculating p-values, on the other hand, can only provide evidence against H0 and for H1 (indicated by $P<0.05$). We cannot distinguish whether a large p-value indicates insensitive data or no effect, and hence a p-value does not provide any evidence *for* H0 (Dienes, 2016). Previous studies investigating perceptual binding in own-body contexts have produced conflicting results (including a null result) and hence I anticipated the possibility to find evidence for either H1 or H0. A Bayesian approach also allows continual data collection, unlike frequentist statistics which are problematic for adding data after analysis (Dienes 2016; Savage, 1962). In sum, a Bayesian analysis provides a better estimate of the required sample size to produce substantial evidence and is generally more informative in terms of null results.

Priors. Bayesian analysis requires a specification of the theory which is tested against H0 (i.e., the probability of different effects given the theory, Dienes, 2014). To specify a plausible predicted effect size P, I took the average of previously reported findings which resulted in 20ms (Hoover & Harris, 2012; Ide & Hidaka, 2013; Keys et al., 2018; Zopf et al., 2015). My theory allows effects to go in either direction based on contradicting findings in the literature. I used the same prior for both comparisons. Previous studies looking at different hand orientations and different objects (hands versus inanimate objects) have found very similar effect sizes for the two comparisons. Zopf et al. (2015), for example, compared a hand with dots in Experiment 1 and found an effect size of 19ms. In their second experiment, the authors tested for an egocentric versus an allocentric hand orientation and found an effect of 18ms. Based on these results I used the same prior (20ms) for both hypotheses. I calculated the Bayes factor in MATLAB with a script downloaded from Dienes' online calculator.[3] This script can also be accessed via the OSF site for this project. I specified a normal distribution with the mean set to zero, the standard deviation set to 20 and the tails set to two-sided.

Planned and preregistered comparisons. I used Bayesian hypothesis testing to quantify evidence for the hypothesis that visual cues in terms of form and orientation modulate visuo-tactile temporal perception. To test for effects of object form, I compared the group mean JND for the egocentric hand condition with the group mean JND for the sponge condition. To test for hand orientation, I compared the mean JND for the egocentric hand condition with the group mean JND for the allocentric hand condition. To calculate the Bayes factor I performed two Bayes t-tests for the comparison.

Exploratory Analysis. As a robustness check I performed a sequential analysis of the Bayes factor in JASP[4] using the program's default priors.

To visualise data, I used the R statistical computing environment and language, including the R package ggplot2 (Wickham, 2009).

2.2 Results

2.2.1 Exclusions

Performance outliers. There were six participants with a JND that was larger than three standard deviations from the group mean for at least one of the three conditions. The group mean was calculated iteratively after collection of each participant's data. I also looked if a curve fit failed

[3] www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference/Bayes.htm
[4] www.jasp-stats.org

to converge on a solution for a sigmoid function for a given condition, which was the case for four out of the same six participants but not for any of the others. Two participants had incomplete datasets due to a technical error or a failure to perform the task. These eight participants were excluded from further analysis. After exclusions, 33 participants (mean age = 26 years, SD = 8 years, 20 female) were included in the analysis.

2.2.2 Just-noticeable difference (JND) for each condition

I calculated the averaged proportion of ‘tactile first’ responses and plotted this against SOAs for the three conditions. As can be seen in Figure 3, the averaged proportions were similar across the three conditions. I then fitted the sigmoid functions to the individual data and calculated JNDs for each participant and condition. Both participants’ individual JNDs and the group mean JNDs for the three conditions are depicted in Figure 4, which shows that variability between participants was high. This might be attributable to different skill levels for performing the task or variations in attentiveness. Indeed some participants reported the task as very challenging whereas others did not. From Figure 4 it can also be seen that the mean JNDs are very similar for the three conditions: egocentric hand mean JND = 104ms, SD = 45ms, 95%CI [88, 119], allocentric hand mean JND = 102ms, SD= 42ms, 95%CI [87, 116] and sponge mean JND = 102ms, SD = 46ms, 95% CI[86, 118]. The mean difference for the egocentric hand versus sponge comparison was 1.39ms, 95% CI[-3.50, 6.28] and for the egocentric hand versus allocentric hand comparison this was 1.48ms, 95% CI[-4.94, 7.88].

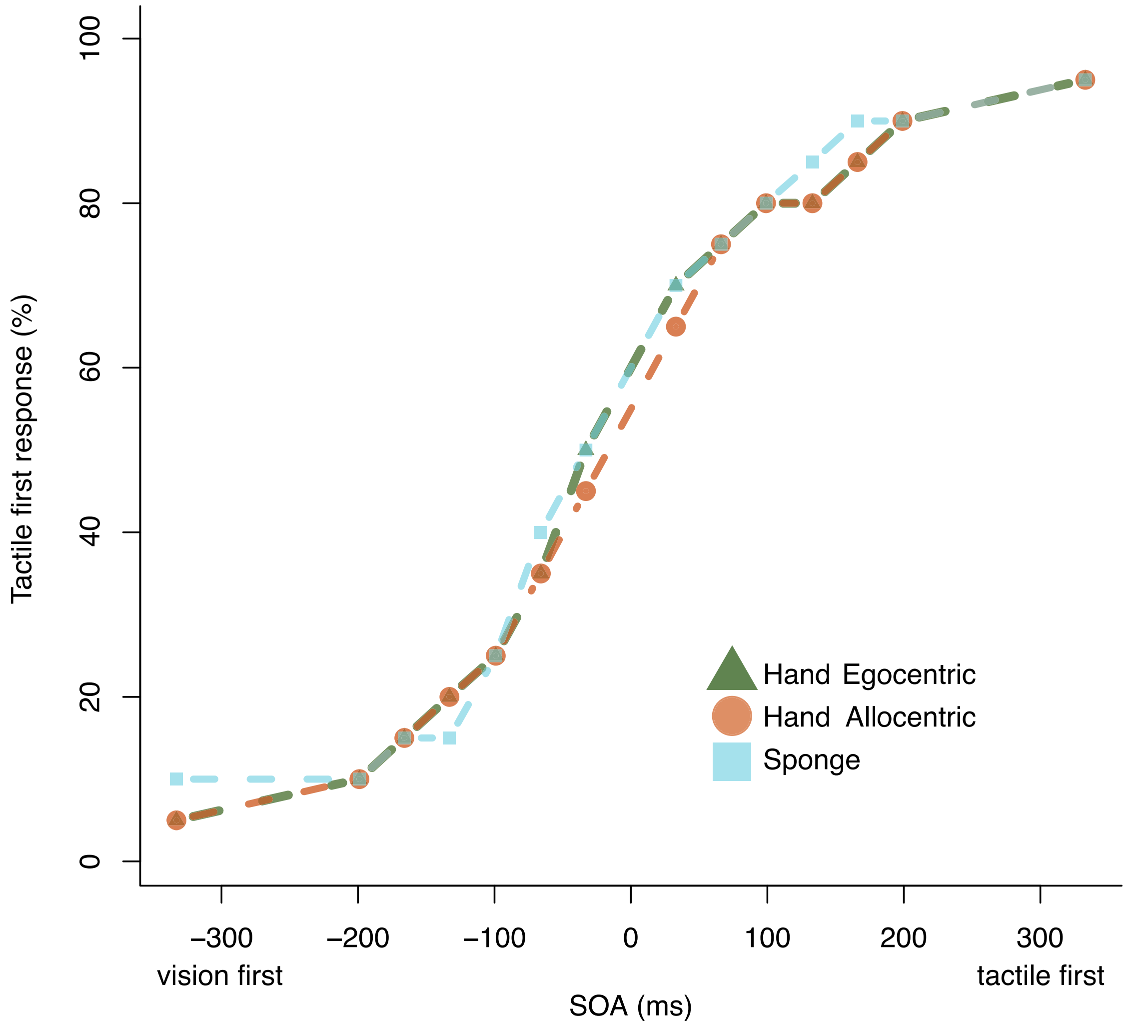

Figure 3: Averaged proportion of ‘tactile first’ responses plotted against SOAs for the three conditions. As can be seen in this figure, the averaged ‘tactile first’ responses for the different conditions are very similar. For the individual data for each participant and each condition, I fitted sigmoid functions and calculated JNDs using the formula: JND = (75% threshold - 25% threshold)/2.

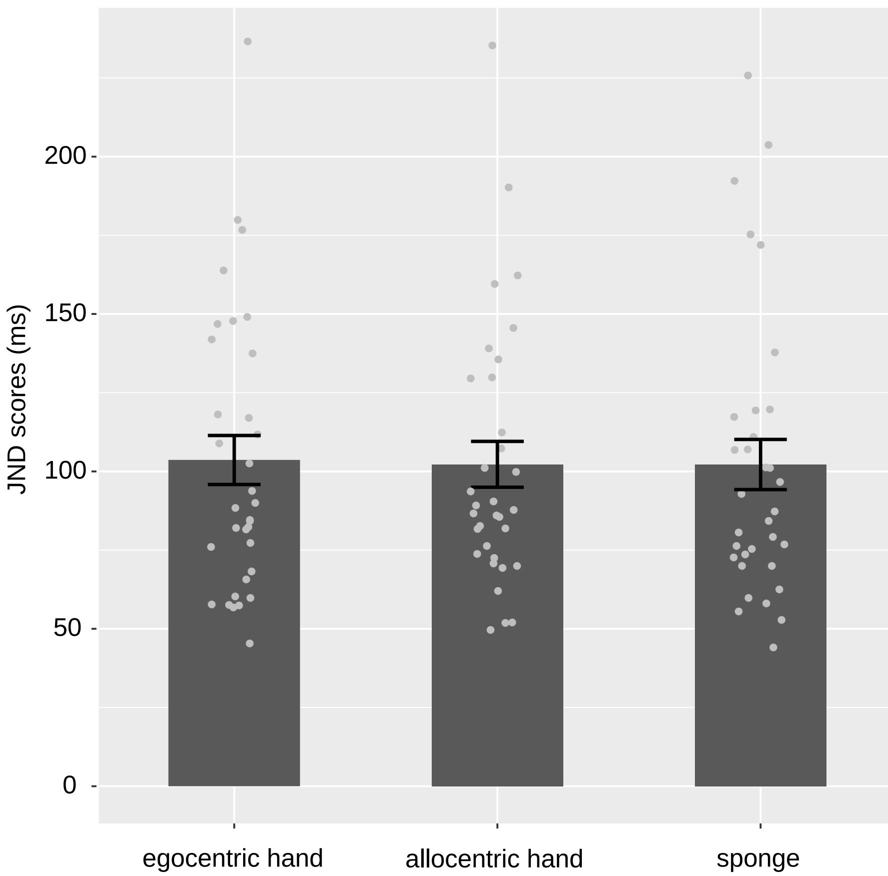

Figure 4: Mean JNDs for each of the three conditions. The error bars represent 95% confidence intervals. Scatter points denote individual data and show high between-subject variability.

Point of Subjective Simultaneity. In addition, for completeness, I also calculated each participant's PSS and the mean results show that overall there was a slight 'touch-first' bias (egocentric hand = -12.02, allocentric hand = -7.95, sponge = -20.16). However, a Bayesian analysis of these mean PSS scores indicates only anecdotal evidence for a difference and the data has not yet converged (egocentric hand vs. sponge, B = 1.42, egocentric hand vs. allocentric hand, B = 0.29). There are many reasons why the PSS can be different from 0, for example, due to stimulus intensity as more intense stimuli tend to be processed quicker (Jankowski & Verleger, 2000), differences in neural transmission speeds (Wada, Yamamoto & Kitazawa, 2004), individual differences (Mollon & Perkins, 1996) and the modality on which one focusses (Shore, Spence & Klein, 2005). These are all plausible explanations for a potential bias but none of these should have influenced the strength of temporal binding (Parise & Spence, 2009).

2.2.3 Bayesian analysis of mean differences

Bayes factor. I calculated the Bayes factor with a Bayes t-test, to investigate whether there is evidence that the visual presentation of touch to a human hand modulates visuo-tactile temporal perception. I compared the group mean JND between the egocentric hand and sponge condition. Figure 5 depicts the development of the Bayes factor as a function of the number of participants tested. As data accumulates with more participants being tested, evidence converges and the Bayes factor increasingly supports H0 as indicated by values smaller than 1 (Gronau & Wagenmakers, 2017). Sequential analysis of the Bayes factor does not require any corrections and can simply be monitored as more data are collected (Wagenmakers et al., 2012). Results indicate moderate evidence (B = 0.178) that object form did not have an influence on the reliability of participants' estimates. Or in other words, this Bayesian analysis reveals that the data were 5.61 (1/0.178) times more likely under H0 than the H1.

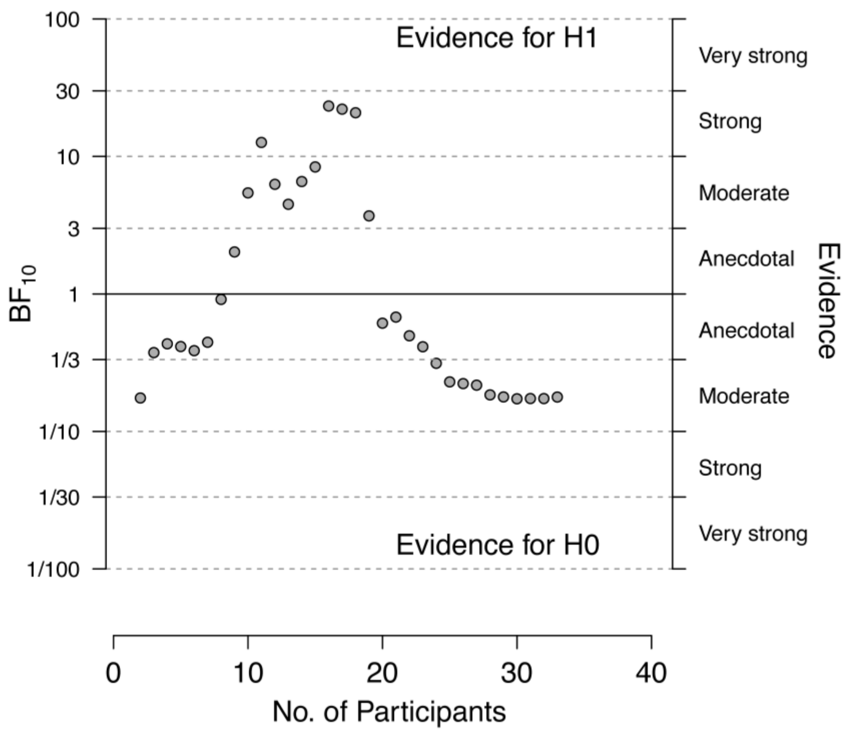

Figure 5: Sequential analysis plot of the Bayes factor for mean group differences between the two conditions: egocentric hand and sponge. As the number of participants grows, the ratio of the likelihood increases in favour of H0. Note that evidence for the alternative hypothesis is strong up to N = 18 but that this is likely due to noise (relatively small sample size and large variability). The Bayes factor starts to converge at N = 20 and provides moderate evidence to support H0.

I further tested if hand orientation modulates visuo-tactile TOJs by comparing the group mean JND between the egocentric hand and allocentric hand condition (see Figure 6). A Bayes t-test indicates moderate evidence (B = 0.144) that the JND for the two conditions is not substantially different. In other words, this Bayes analysis reveals that the data were 6.94 (1/0.144) times more likely under H0 than H1.

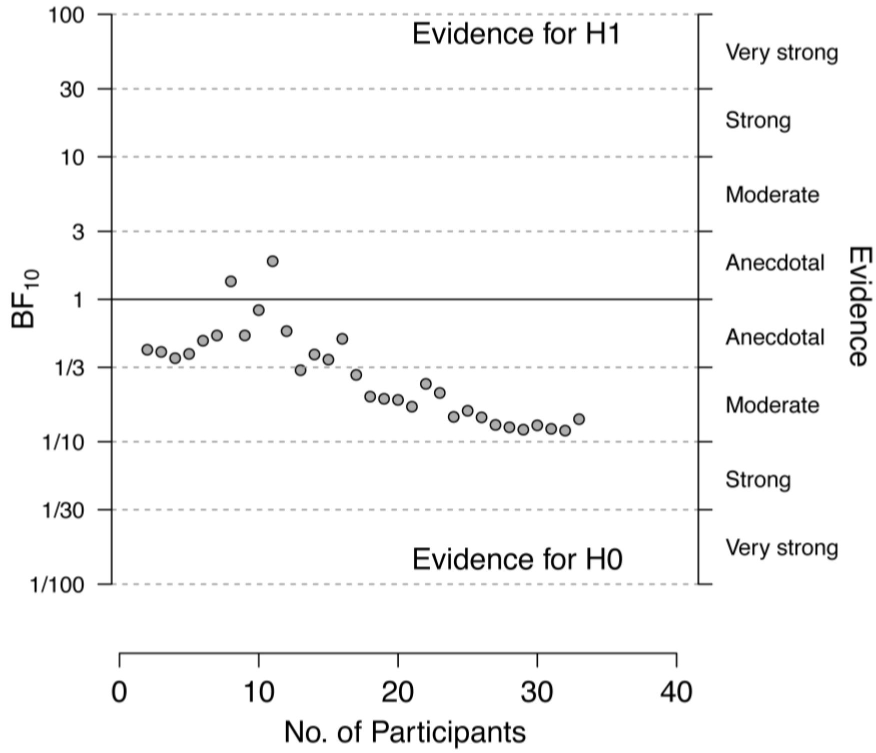

Figure 6: Sequential analysis plot of the Bayes factor for mean group differences between the two conditions: egocentric hand condition and allocentric hand. As the number of participants grows, the ratio of the likelihood increases in favour of H0. The Bayes factor starts to converge at N = 24 and provides moderate (approaching strong) evidence to support H0.

Results demonstrate that cumulative evidence converges in support of H0 for both comparisons at N = 19 and N = 23. Interestingly, N = 11 in Figure 5 already depicts a Bayes factor of 12.7, and N = 16 even shows a Bayes factor of 23.3, which suggests strong evidence for H1 (that temporal binding effects are substantially different between the two conditions: egocentric hand and sponge). However, as the Bayes factor has not converged at this stage, these findings are likely due to noise. This highlights not only the benefits of Bayesian analysis over conventional frequentists analysis, but also the importance of testing large sample sizes to obtain reliable estimates and avoid false positives.

Further, in my preregistration I specified that I would continue data collection until both t-tests had reached a Bayes factor of 10, indicating strong evidence (Jeffreys, 1998; Rouder et al. 2009). I also specified that when restricted due to time limitations, I would accept a Bayes factor of larger than 3 as sufficient evidence (Dienes, 2016). As I only reached a Bayes factor of 10 for one of the comparisons I continued data collection beyond the initial 16 participants. I finished testing in October (due to time restrictions), before either of the Bayes factors (after convergence) had reached 10.

Robustness check for set priors. For my analysis I used an informed prior (20ms in both directions) which I based on previous studies with similar experiments. The variance of the prior distribution reflects the level of uncertainty regarding the value of the parameter of interest. A smaller prior variance indicates a higher level of certainly about the parameter value. An informative prior (as opposed to a non-informative prior or weakly-informative prior) contains information that is relevant to the estimation of the model and consequently may have a large impact on final estimates (van de Schoot & Depaoli, 2014). To provide insight into the impact of the used prior on my analysis, I also performed a sequential analysis of the Bayes factor in JASP and used the program's default (non-informative) wider priors. Figure 7 shows that this did not affect the outcome of the results, which adds to the robustness of my conclusions.

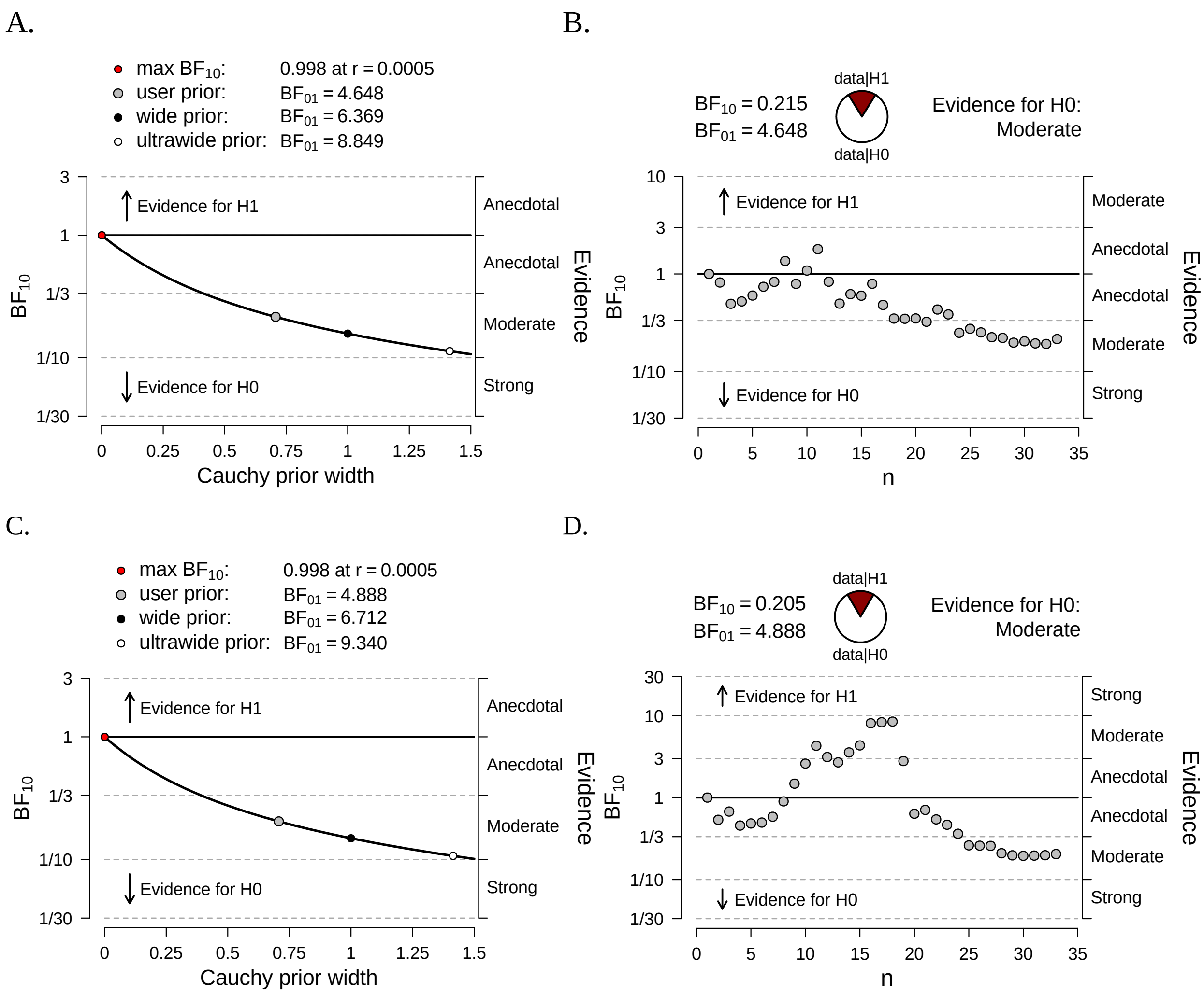

Fig 7. JASP Bayes factor robustness check for (A) the egocentric hand vs. sponge comparison and (C) the egocentric hand vs. allocentric hand comparison, including the prior initially used (user prior), a wide prior and an ultrawide prior. A wider prior reflects a higher degree of uncertainty which in these cases results in relatively stronger evidence to support the H0. The JASP sequential analysis of the Bayes factor with a default prior for (B) the egocentric hand vs. sponge comparison and (D) the egocentric hand vs. allocentric hand comparison, shows a very similar degree of evidence (moderate) for the H0 across priors. The proportion wheel at the top provides a visual impression of the strength of evidence that the Bayes factor provides. The red area represents support in favour of H1 and the white area represents support in favour of H0.

Exploratory analysis. To screen for MTS, participants also filled out a short synaesthesia questionnaire and a MTS screener. In turned out that two participants had a score above 7 (10 and 12) on the MTS screener, which Ward et al. (2018) take as a potential indication of MTS. To ensure that the data from these two potential MTS participants did not affect the result, I also calculated the Bayes factor without data from these two participants, which did not change the pattern of results (mean difference egocentric hand vs. sponge = 1.53ms, B = 0.19, mean difference egocentric hand vs. allocentric hand = 1.89ms, B = 0.17).

Participants also filled out a short empathy questionnaire which was divided into three categories: cognitive empathy, social skills and emotional reactivity (Muncer & Ling, 2006). I tested for correlations between participants' individual JND difference scores (for the egocentric hand and sponge condition) and their self-reported level of empathy. A Bayesian analysis demonstrated positive correlations for cognitive empathy (r = 0.36, B = 1.69) and social skills (r = 0.39, B = 2.47) but not for emotional reactivity (r = -0.14, B = 0.29). However, the Bayes factor indicates that the strength of evidence should be considered anecdotal.

Overall, these results suggest that viewing videos of a touch being applied to plausible or implausible visual stimuli for one's hand (hand oriented plausibly, hand rotated 180 degrees, sponge) while also being touched, does not modulate the TOJ of visual and tactile stimuli.

2.3 Discussion

In this experiment, I tested the influence of visual body-ownership cues on visuo-tactile TOJs in a (predominantly) non-synaesthete sample. I manipulated the visual stimuli in terms of visual plausibility for one's body by comparing a human hand with a sponge (object) and an egocentric hand with an allocentric hand (orientation). I calculated the ratios of 'tactile first' responses for each SOA and calculated participants' JND for each of the three conditions. A Bayesian analysis of the data indicates no substantial difference in group mean JNDs for either of the comparisons (form and orientation). I also screened for MTS, which indicated that two participants in this sample might have MTS. However, excluding data from these two participants did not change the pattern of results.

Given the previous findings of visuo-tactile studies (Ide & Hidaka, 2013; Maselli et al., 2016), these results are surprising. My study incorporated highly realistic visual stimuli which were matched more convincingly with the tactile stimuli, and hence I expected larger JNDs for the plausible egocentric hand condition compared to the two implausible conditions, indicating a relatively stronger coupling.

An important element that differed between this study and the other visuo-tactile studies (Ide & Hidaka, 2013; Keys et al., 2018; Maselli et al., 2016) is the spatial discrepancy between the visual and tactile stimuli. Spatial position can be used as a redundant cue and hence might make the temporal order of stimuli more salient (Spence et al., 2003). Ide and Hidaka (2013) presented the visual stimuli on a computer screen and the tactile stimuli on the participant's hand placed to the left, which resulted in a relatively large distance between the visual and tactile stimuli. The space between the stimuli was kept consistent across the conditions, but the plausible hand image (and not the implausible hand or arrows) could have induced a shift in perceived location of the real hand, reducing the subjective space between the visual and tactile stimuli. The three conditions were blocked, which may have facilitated changes in body-representations. Comparatively, the visual and tactile stimuli in the current study and the study by Keys et al. (2018) were presented much closer in space. Keys et al. (2018) argue that this may have led to the difference in results between their experiment and the previous study. However, in the study by Maselli et al. (2016), visual and tactile stimuli were presented at the same location (the virtual rotating geared-wheel was actually touching a virtual finger in the touch-conditions) and this study produced similar results as Ide and Hidaka (2013). Hence it seems that spatial discrepancy cannot explain the difference in findings.

A more plausible explanation is that previous findings (Ide & Hidaka, 2013; Maselli et al., 2016) could be unreliable due to small samples sizes (12 and 14 respectively). The study by Keys et al. (2018) had a sample of 30 participants and found substantial evidence to support the null hypothesis that there is no significant different in asynchrony detection threshold between a plausible hand orientation and an implausible hand orientation. My study had a similar sample size (33 participants after exclusions) and found the same pattern of results for TOJs. In addition, at a similar number of participants (N=16) as previous studies (Ide & Hidaka, 2013; Maselli et al., 2016), my results do indicate strong evidence for an effect, which provides concerning evidence that small sample sizes can result in inaccurate conclusion (Button et al., 2013; Cumming, 2014; Dienes, 2016). Further, as my study and the study by Keys et al. (2018) used different tasks (synchrony judgement and temporal order judgement), we can also conclude that the findings are not due to task differences. This provides compelling evidence for the null hypothesis, that plausible visual cues for one's body do not modulate visuo-tactile temporal perception.

In this Experiment, I also explored whether temporal binding effects were correlated with participants' empathy scores. Previous studies suggest that empathy reflects a combination of several cognitive mechanisms, which include shared representations for actions (Rizzolatti & Craighero, 2004), emotions (Wicker, Keysers, Plailly, Royet, Gallese & Rizzolatti, 2003) and somatosensation including touch (Keysers, Kaas & Gazzola, 2010), that are activated when an individual is in that state or observes someone else in that state (Ward et al., 2018). The Threshold Theory proposes that MTS relies on a hyper-active mirror-system for touch (somatosensation) and hence MTS might be an extreme form of normal empathy (Banissy & Ward, 2007; Ward et al., 2018). Ward et al. (2018) tested for different categories of empathy, which were cognitive empathy (predicting others' thoughts and feelings), social skills (being able to interact with others appropriately) and emotional reactivity (intuitively understanding how people feel) and found that only the latter was increased in MTS. This suggests that MTS taps more into shared emotions and feelings rather than reasoning about mental states. If the Threshold Theory is correct and MTS lies on a continuum, we might expect that non-synaesthetes that scored high on emotional reactivity would show larger JNDs for the egocentric hand compared to the sponge condition than those who scored low on emotional reactivity. However, results suggest that emotional reactivity scores were not positively correlated with differences in temporal binding effects, but that cognitive empathy and social skills were. These findings should only be considered as anecdotal evidence (due to a small Bayes factor), but might suggest that stronger mappings between vision and touch are not associated with emotional reactivity (see also Baron-Cohen, Robson & Allison, 2016).

Based on the findings from Experiment 1, I conclude that visual body-ownership cues do not affect visuo-tactile temporal perception in a non-synaesthete sample. However, it is possible that temporal binding effects in this group are small and that this TOJ task was not able to pick up on these effects. It is therefore interesting to also test a MTS sample, as I predict that crossmodal associations between vision and touch are stronger in these individuals, potentially resulting in more pronounced temporal binding effects. In the following chapter, I test whether binding between visual and tactile stimuli is altered in MTS and if this affects temporal perception.

Chapter 3: The effect of viewing touch to a hand on visuo-tactile temporal order judgements in mirror-touch synaesthetes (Experiment 2)

The aim of the second experiment was to explore whether observing touch to a human hand modulates the temporal perception of visual and tactile stimuli in individuals with MTS. In line with the Threshold Theory, I predicted stronger binding effects for the two hand conditions (compared to the sponge condition) in this sample relative to the non-synaesthete sample. As explained by the Self-Other Theory, MTS might have difficulty distinguishing self from others, and hence I predicted smaller effects of visual hand orientation on temporal binding.

A sample of seven potential MTS was recruited based on a short synaesthesia questionnaire and a subsequent email with questions about subjects' experiences of seeing and feeling touch. These participants performed the same TOJ task as used in Experiment 1 and also filled out the MTS screener, plus I conducted an interview about their personal experiences. Two raters assessed the data and separately concluded that three of these participants clearly matched the profile of a MTS. I performed Bayesian single-case analyses comparing the JND condition differences from these three individual MTS with the non-synaesthete group mean JND condition differences.

3.1 Method

3.1.1 Participants

Potential MTS were selected based on short synaesthesia questionnaire (see Appendix B) which included one question to assess MTS ('When I see someone else being touched, I experience touch myself'). A total of 28 out of 129 subjects had answered yes to this question. In addition, two participants out of the non-synaesthete sample scored high on the MTS screener (Ward et al., 2018) and hence I included these persons as well. I emailed these 30 individuals a list of questions (see Table 1) related to MTS and based on their answers I recruited seven potential

MTS (which included one individual from Experiment 1), all of whom were right-handed with normal or corrected-to-normal vision (mean age = 25 years, SD = 12 years, 6 female).

Table 1: Questions emailed to an initial sample of 30 potential mirror-touch synaesthetes.

1. Explain what it feels like when you see someone else being touched.
2. Do you experience the touch on the same part of your body as the person being touched?
3. How often do you experience this?
4. Have you experienced this your whole life or only as a child/adult?
5. Do these experiences affect you positively or negatively in any way?
6. Do you know whether you have other types of synaesthesia?
7. Do you have other ‘unusual’ or uncommon perceptual experiences?

3.1.2 Design and procedure

During the test sessions, each participant performed the same TOJ task as in Experiment 1 (besides the one participant from the first sample, I used her data from Experiment 1). This was followed by the MTS screener and a 20-minute interview about the participant’s personal experiences (for a transcript of these interviews see Appendix C).

3.1.3 Data analysis

I compared the data from the individual MTS to the non-synaesthete group means (which were calculated without data from the two potential MTS, N = 31) from Experiment 1. I first calculated each participant’s JND across the three experimental conditions and established the difference in JNDs for the two comparisons (egocentric hand vs. sponge and egocentric hand vs. allocentric hand). I used Bayesian single-case analyses to assess if there were any substantial differences between the individual MTS and the non-synaesthete group (Crawford & Garthwaite, 2007). Finally, for completeness, I calculated each participant’s PSS to establish any bias towards the visual or tactile stimulus (Vroomen & Keetels, 2010).

Data exclusion. Two raters looked separately at the results from the MTS screener and a transcript of the interviews and both concluded that the same three participants convincingly matched the profile of a MTS (mean age = 21 years, SD = 4 years, 3 female). Any participant that was not considered a MTS by one or two of the raters was excluded from further analysis. Participants were also excluded if any of the three curves (representing the three conditions) failed to converge on a solution for a sigmoid function. Incomplete datasets due to a technical error or a failure to perform the task were omitted as well. Any participant who was rated a MTS but whose data could not be fitted or was incomplete due to a technical error was invited in for a second testing session and I only used the new data for analysis.

Planned comparisons. I used Bayesian single-case analyses to compare data from the individual MTS with the non-synaesthete group to test the predictions that: 1) the difference in temporal binding for the egocentric hand versus the sponge condition would be larger for MTS than for non-synaesthetes (indicated by a larger difference in JNDs between the conditions); and 2) that in the MTS sample, hand orientation would have a smaller effect (as indicated by a relatively smaller difference between the egocentric hand JND and the allocentric hand JND). I also calculated a point estimate of the percentage of the non-synaesthete population that would obtain a higher score. For this analysis I used the program SingleBayes.exe[5] (Crawford & Garthwaite, 2007).

To visualise the data I used the R statistical computing environment and language, including the R package Psycho (Makowski, 2018) and the ‘Crawford-Garthwaite (2007) Bayesian test for single-case versus group’ script from cran.r-project.org[6].

[5] https://homepages.abdn.ac.uk/j.crawford/pages/dept/BayesSingleCase.htm
[6] https://cran.r-project.org/web/packages/psycho/vignettes/overview.html

3.2 Results

3.2.1 Exclusions

Performance outliers. Data from one of the MTS participants failed to converge on a solution for a sigmoid function. This participant was retested in a second testing session and the first data set was excluded from analysis.

3.2.2 Just-noticeable difference (JND) for each condition

Just-noticeable difference. I calculated each participant's JND for the three conditions and established the difference for the two comparisons (egocentric hand vs. sponge and egocentric hand vs. allocentric hand, for an overview of the results see Table 2). Results show that for two out of the three MTS participants, JNDs for all three conditions are higher than the non-synaesthete group mean (these MTS results fall outside of the 95%CI for this group). This might suggest that MTS generally have less sensitivity to temporal order when seeing and feeling touch, both when observing touch to a hand and to an object. Looking at the individual different scores however, indicates high between subject-variability and demonstrates no clear pattern of results.

Table 2: Overview of results comparing mirror-touch synaesthetes to the non-synaesthete group mean (the non-synaesthete group mean is calculated without data from the two potential mirror-touch synaesthetes from Experiment 1).

MTS participants	JND egocentric	JND sponge	JND allocentric	Difference ego/sponge	Difference ego/allo
1	82.69	76.63	83.15	6.06	-0.46
2	136.28	124.63	131.74	11.65	4.54
3	149.27	163.46	135.44	-14.20	13.83
Non-synaesthete group mean	105.79 SD = 45.23 95% CI [89, 122]	104.26 SD = 42.56 95% CI [89, 119]	103.90 SD = 46.40 95% CI [87, 120]	1.53 SD = 19.37 95% CI [-5, 8]	1.89 SD = 14.58 95% CI [-3, 7]

Point of Subjective Simultaneity. The mean PSS for the three participants was egocentric hand (94.63), allocentric hand (91.32), sponge (17.03) which seems to suggest a considerable 'vision-first' bias, especially for the two hand conditions. However, looking at the individual data (see Table 3) shows that two participants had a negative PSS score for the three conditions, indicating a 'touch-first' bias and one participant had a large positive PSS score for the three conditions, indicating a 'vision-first' bias. Hence we cannot reliably interpret the group data because of the individual variability.

Table 3. PSS scores for the three mirror-touch synaesthetes. There appears no consistent bias towards either the 'vision-first' or 'tactile-first' situation.

Mirror-touch synaesthetes	PSS egocentric hand	PSS allocentric hand	PSS sponge
1	-121.32	-109.47	-117.78
2	-19.00	-30.08	-74.50
3	208.27	212.72	108.56
mean	94.63	91.32	17.03

Empathy scores. I also looked at the empathy scores for these individuals, which showed that the three MTS scored higher than non-synaesthetes on all empathy categories (cognitive empathy scores; 9, 9, 10 vs. the non-synaesthete group mean 5.36, social skills scores: 5, 5, 7 vs. the non-synaesthete group mean 4.30, emotional reactivity scores; 6, 9, 7 versus the non-synaesthete group mean 5.67).

3.2.3 Bayesian single-case analyses

I compared condition JND differences from the individual MTS with the group mean condition JND differences. If visual cues about form would have resulted in stronger binding effects in MTS, data of these individuals would lie outside of the non-synaesthete group data (on the right of the graph). Relatively weaker binding effects for hand orientation in MTS compared to non-synaesthetes, would also lie outside of the non-synaesthete group data but on the other side (on the left of the graph). Figure 8 shows the difference scores and clearly demonstrates that data for all three MTS lies within the non-synaesthete group data, indicating no difference.

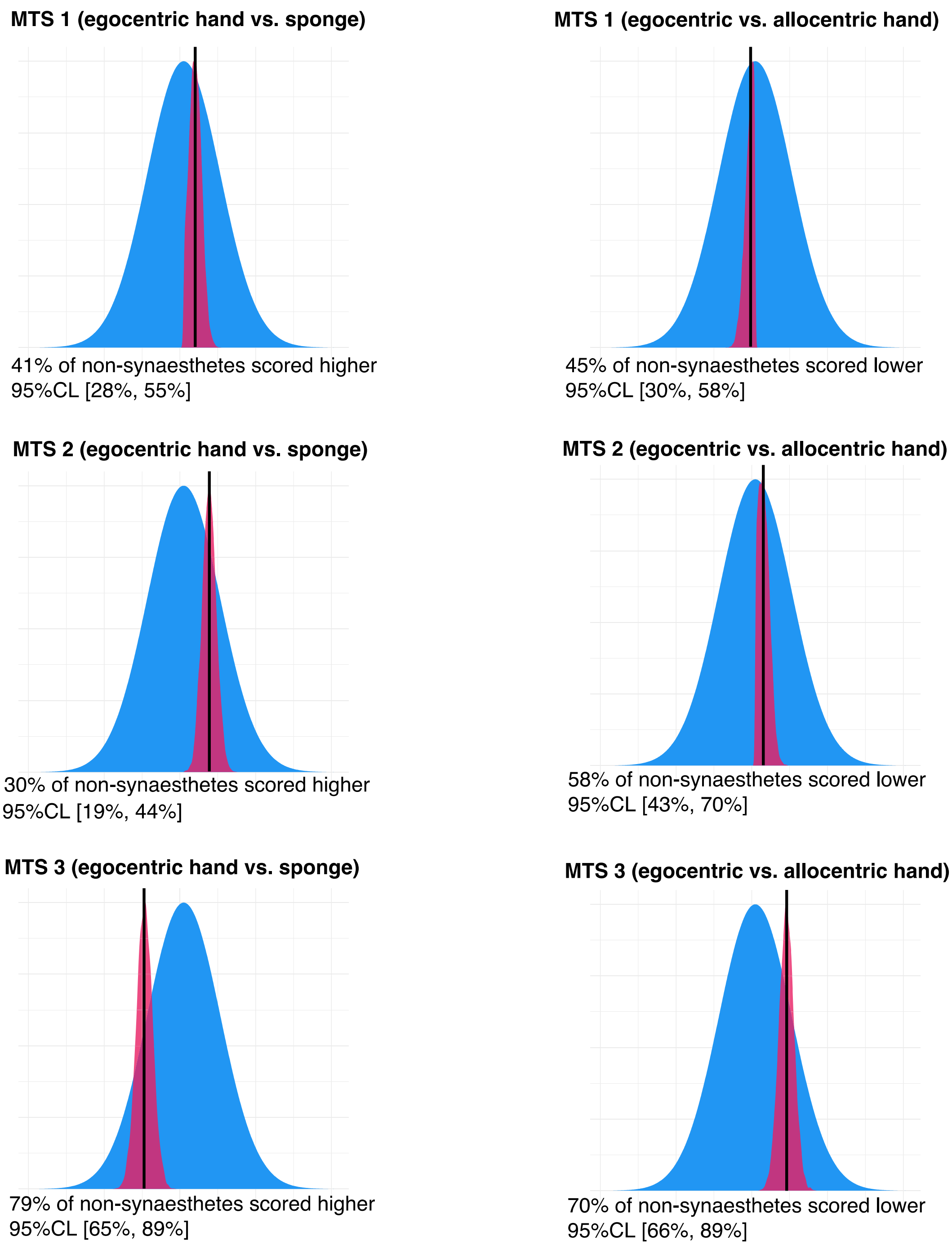

Figure 8. The difference scores for the three mirror-touch synaesthetes based on the Crawford-Garthwaite (2007) Bayesian test for single-case vs. group. The blue area represents data for the non-synaesthete group (mean = 1.53, SD = 19.37 for the egocentric hand vs. sponge comparison and mean = 1.89, SD = 14.58 for the egocentric hand vs. allocentric hand comparison). The black line represents data (difference in JND between conditions) from the individual MTS participants. The pink area represents the 95% upper and lower Bayesian credible limits (CL) on the percentage of non-synaesthetes that scored higher or lower. Data show that the JND differences of all three mirror-touch synaesthetes were not different from the non-synaesthete sample.

3.3 Discussion

In this experiment, I tested the influence of visual body-ownership cues (form and orientation) on visuo-tactile temporal perception in three individuals with MTS. The Threshold Theory proposes that MTS is caused by a hyper-active mirror system for touch. In line with this, I predicted that in these individuals, crossmodal associations between vision and touch would be stronger resulting in more pronounced visuo-tactile temporal binding effects on a TOJ task (as evidenced by a larger difference in JNDs between the egocentric hand and sponge condition compared to the non-synaesthete group). Contrary to my prediction, Bayesian single-case analyses provide *preliminary* evidence to suggest that there is no difference in the effect of visual body-ownership cues on temporal binding in MTS compared to non-synaesthetes.

Looking at separate JND scores however, indicates that two out of three MTS had larger JNDs for all three conditions compared to the non-synaesthete group. It is possible that MTS generally show less sensitivity to temporal conflicts when viewing touch. Alternatively, these findings might suggest that MTS experience some degree of synaesthetic touch both when viewing touch to a human and touch to an object. However, all three MTS reported that during the experiment they felt a touch on their own hand when viewing touch to the hands but not to the sponge (see Appendix C for a transcript of the interviews). One participant did mention during the interview that as a child she used to feel touch when observing touch to certain objects (such as plush toys). The current literature on MTS reflects this uncertainty as to whether synaesthetic touch is restricted to viewing human touch. For example, the study by Ward et al. (2018) reported that some individuals who scored high on their MTS screener also reported tactile experiences for objects (although weaker than for humans, see also Baron-Cohen et al., 2016). This goes against claims previously made that MTS only experience synaesthetic touch when observing human touch (e.g., Banissy & Ward, 2007; Holle, Banissy, Wright, Bowling & Ward, 2011). Future studies could further investigate the effects of viewing touch to a hand compared to an object on visuo-tactile temporal binding to clarify this issue.

In addition, the Self-Other Theory proposes that individuals with MTS have difficulty distinguishing self from other. Hence, I predicted that the effects of hand orientation would be less strong in MTS compared to non-synaesthetes. However, results from Experiment 1 already showed no effect of hand orientation on visuo-tactile temporal binding in the non-synaesthete group (as indicated by no substantial difference in JNDs between the egocentric hand and allocentric hand). As a result, the findings from Experiment 2 provide no further insight into the effects of hand orientation on temporal binding in MTS.

I also looked at levels of empathy in MTS and results show that these participants scored higher on all empathy categories compared to the non-synaesthete group. This might suggest that MTS is indeed associated with increased empathy, though not with emotional reactivity specifically. However, we do have to be mindful when interpreting the strength of evidence from Experiment 2 because of the small sample and hence a limited amount of data.

It is furthermore interesting to note some remarkable observations from the interviews in this study (see Appendix C). All three MTS participants mentioned during the interview that observing various kinds of touch result in different sensations on their own bodies. Kind touch results in a pleasant sensory experience whereas painful or unkind touch elicits an uncomfortable sensation. Two participants furthermore reported that pleasant touch is accompanied by a distinctly warm sensation but that unpleasant touch (for example from the knife in the videos) results in a cold sensation. It would be interesting to further investigate these phenomenological experiences in MTS. In addition, several participants (both MTS and non-synaesthetes) reported that during the experiment, the viewed and felt touch were accompanied by an internally perceived musical rhythm. Whenever the rhythm ‘felt out of order,’ participants would know to press the other response key which they perceived helped them to perform the TOJ task. This seems to indicate explicit associations between vision, touch and audition in both people with and without synaesthesia, something that future studies could investigate.

It is important to highlight that Experiment 2 was set out to be exploratory and we cannot reliably draw conclusions. This becomes particularly evident when looking at individual MTS data which shows that between-subject variability is high. Nonetheless my study provides valuable insights into MTS and interesting avenues for future research.

Chapter 4: General discussion

The aim of this thesis was to examine whether visual body-ownership cues modulate visuo-tactile temporal perception in non-synaesthetes (Experiment 1) and whether this is different in individuals with MTS (Experiment 2). In the following section, I summarise my research findings and discuss the implications for understanding body perception and MTS. I cover several limitations of the present study and suggest how future research might address these to answer some of the remaining open questions.

4.1 The present study

In Experiment 1, I investigated the effects of object form (egocentric hand vs. sponge) and orientation (egocentric hand vs. allocentric hand) on visuo-tactile TOJs in non-synaesthetes. I calculated the averaged proportions of 'tactile first' responses against SOAs and calculated the difference in group mean JNDs between the form and orientation conditions. I found moderate evidence with a Bayesian analysis that neither object form nor orientation modulate visuo-tactile temporal binding in this group. Based on the results from the first experiment, I conclude that visual body-ownership cues do not enhance temporal binding of visual and tactile stimuli in non-synaesthetes. However, it is possible that these binding effects are only small in non-synaesthetes and that a TOJ could not pick these up. Hence I also tested MTS as I predicted that in these individuals vision and touch would be more strongly associated.

In Experiment 2, I examined the effects of visual body-ownership cues on visuo-tactile temporal binding in MTS. The Threshold Theory proposes that MTS relies on 'normal' perceptual mechanisms, and that these are simply exaggerated or hyperactive in synaesthetes. Further, studies suggest that MTS only experience synaesthetic touch when they observe touch to humans but not to objects (Banissy & Ward, 2007; Holle et al., 2011). Hence, I predicted that in these individuals temporal binding effects for the egocentric hand (but not the sponge) would be stronger than in non-synaesthetes. Contrary to my prediction, Bayesian single-case analyses provide preliminary evidence that neither of the three MTS were different from the non-synaesthetes in terms of JND differences between the egocentric hand and sponge. However, two of the three MTS did show larger JNDs for all three conditions, suggesting that perhaps MTS are generally less sensitive to the temporal order of visual and tactile stimuli when viewing touch, or that both touch to a person and touch to an object elicits a synaesthetic touch experience.

Based on the findings from both experiments, I conclude that visual body-ownership cues in terms of form and orientation do not modulate visuo-tactile temporal binding in either non-synaesthetes or MTS. This is in contrast with reports from previous studies that did find an effect. I will now discuss several potential reasons for this discrepancy in findings.

4.2 How can the absence of visuo-tactile temporal binding in own-body contexts be explained?

Both the study by Ide and Hidaka (2013) and Maselli et al. (2016) reported an effect of visual body-ownership cues on visuo-tactile temporal perception, whereas the current study and the study by Keys et al. (2018) found substantial evidence for the null hypothesis. As mentioned in the introduction, several factors may explain this discrepancy in findings across these three visuo-tactile studies, such as specific task demands, varying ecological validity and differences in sample size. I addressed these potential factors in the current study, which involved a TOJ task with highly realistic visuo-tactile stimuli pairings and a sufficiently large sample. As I did not find an effect in Experiment 1, which is in line with the null results reported by Keys et al. (2018), it seems likely that visual body-ownership cues in terms of form and orientation do not enhance visuo-tactile temporal perception.

The current study, combined with the findings by Keys et al. (2018), provide compelling evidence to suggest that visual information about the hand does not influence the unity assumption for visuo-tactile signals. Previous studies also reported that visual cues plausible for one's body, did not result in decreased visuo-proprioceptive perception (Hoover & Harris, 2012, 2015; Zopf et al., 2015). Hence it is possible that the unity assumption generally does not modulate multisensory temporal integration in own-body context. This is also in line with the reported absence of temporal binding effects in the audio-visual domain (Keetels & Vroomen, 2012; Vatakis & Spence, 2008), which suggests that effects from the unity assumption might be specific to speech stimuli (Angelaki & Spence, 2014). Thus, a Bayesian integration model for body-ownership might account for the observed effects of visual information on *spatial binding*, but it cannot account for the lack of *temporal binding*.

So how can previous findings for an effect of visual body-ownership cues on visuo-tactile temporal binding be explained? The Bayesian analysis used in the current study provides a much more reliable estimate of the strength of evidence compared to the conventional statistical analysis used in the previous studies, and suggests that previously reported visuo-tactile binding effects might be due to small samples.

4.3 The benefits of Bayesian analysis and the importance of large samples

Previous studies that have reported an effect of visual body-ownership cues on visuo-tactile temporal binding included small samples (12 and 14 participants). We cannot rule out the possibility that these findings are due to low statistical power. This becomes particularly evident when looking at the results of the current study which indicate high between-subject variability in terms of JNDs. This adds noise and increases the problem of small samples. In addition, the sequential analysis of the Bayes factor (especially for the egocentric hand vs. sponge comparison), shows that for the first participants the data appear to provide strong evidence for an effect at N = 11 (B = 12.7) with an even higher Bayes Factor at N = 16 (B = 23.3) but the estimate is very noisy and is not a convergence. This highlights the importance of sequentially plotting the Bayes factor as this provides insight into whether the results should be attributed to noise. Only after testing 19 participants in Experiment 1, and 23 participants in Experiment 2, did the Bayes factor start to converge which indicates sufficient data has been gathered to draw reliable conclusions. Testing more participants would likely have provided stronger evidence to support H0, because once data converge in a clear direction, this should theoretically not exceed a value in the opposite direction due to accumulation of more data (Dienes, 2016; Rouder, 2014; Savage, 1962). Thus, this Bayesian approach combined with a larger sample provides a much more reliable estimate of the strength of evidence compared to the conventional statistical approach and small samples used in the previous studies.

Another important benefit of using Bayesian statistics is that one can specify a prior distribution of possible population parameter values which reflects predications based on the theory and previous research findings. This allows researchers to continuously incorporate new findings and personal judgement to update new estimations of parameters for future investigations. Strong predictions (in the form of informative priors with smaller prior variance) contain information that is relevant to the estimation of the model and may have a large impact on final estimates (van de Schoot & Depaoli, 2014). It is therefore important that researchers also perform a robustness check including priors with wider variance (Dienes, 2016). The robustness check in my study shows that the used prior in Experiment 1 did not affect the pattern of results, which adds to the reliability of my conclusions.

Recently concerns have been raised about the degree of false-positive findings in published research (Ioannidis, 2005; Lindquist & Mejia, 2015; Open Science Collaboration, 2015). This may be attributed to flexibility in data analysis, low statistical power and a lack of replication due to publication bias (Rosenthal, 1979; Simmons, Nelson & Simonsohn, 2011; Wasserstein & Lazar, 2016). Several solutions to this problem are formal preregistrations, clearly defining hypothesis-driven and exploratory research, ensuring sufficiently high statistical sensitivity and replication studies (Dienes, 2014; Ioannidis, 2005; Wagenmakers et al., 2012). I formally preregistered the methods and planned analysis of Experiment 1 and combined this with a Bayesian analysis to ensure my data were sensitive enough to provide evidence for either H1 or H0. I have also clearly distinguished that the results of Experiment 2 should be interpreted as exploratory rather than confirmatory. This approach adds to the credibility of my results, which suggest that there are no effects of visual body-ownership cues on visuo-tactile temporal binding and that findings from previous studies might be due to small samples. Hence, future studies incorporating a similar TOJ task should make sure to include significantly large samples and preferably a (preregistered) Bayesian analysis, so that both evidence for H1 and for H0 can be interpreted in a meaningful way.

4.4 Implications for MTS theories

The underlying causes of synaesthesia are currently unknown, although some evidence suggests that it relies on ‘normal’ perceptual mechanism for crossmodal associations which are simply exaggerated in synaesthetes (Martino & Marks, 2001; Newell & Mitchell, 2016; Simner, 2012; Ward et al., 2006). The Threshold Theory in a similar way suggests that MTS is caused by a hyperactive mirror-system for touch (Ward & Banissy, 2015), which might result in a stronger mapping between visual and tactile stimuli in this population. Hence I predicted that visuo-tactile temporal binding effects would be stronger in MTS than in non-synaesthetes when comparing touch to a human hand versus an object. Neither the results from Experiment 1 nor Experiment 2 showed an effect of visual form and orientation cues on temporal binding. However, it is interesting to note that all three MTS participants mentioned that throughout the experiment they consciously experienced a sensation of touch on their own hand when viewing the hand (but not the sponge) being touched, which they perceived made it more difficult to establish the temporal order of stimuli on trials in which a hand was presented. These reports resemble the behavioural effects typically found on a vision-touch interference task which is used to establish MTS (Banissy & Ward, 2007, see also Holle et al., 2011). On this task, participants observe touch to a human body which results in a synaesthetic conscious tactile sensation on their own bodies. This makes it more difficult to establish the location of tactile touch when viewed and felt touch are spatially incongruent. These interference effects are typically absent when observing touch to an object. Contrary to these previous findings, results from Experiment 2 indicate that two out of three MTS showed large JNDs relative to non-synaesthetes, both when observing touch to the hand and to the object. This might suggest that visuo-tactile mappings are stronger in MTS compared to non-synaesthetes and that this results in stronger temporal binding effects both for observing touch to humans and to objects (see also Baron-Cohen et al., 2016; Ward et al., 2018). The literature on this issue is currently ambiguous and future studies could further investigate the effects of viewing touch to a hand compared to an object on visuo-tactile temporal binding in MTS to clarify this. The current study has provided some valuable insights into the behaviours and experience of MTS, but as it included only three MTS participants we should be careful when drawing conclusions.

4.5 Limitations of this study and avenues for future research

Data from the TOJ task were noisy which resulted in high variability between participants. This meant that a large sample was required to increase the strength of evidence. Due to time restrictions, I had to stop data collection before either of the comparisons had reached a Bayes factor of 10. This means that the current data should be interpreted as moderate evidence for the null hypothesis (although this is approaching strong evidence as can be observed in the Bayes plots). As a Bayesian analysis allows for continuous data collection, further testing could increase the strength of this evidence, which would add to the robustness of these findings.

In addition, the Bayes factor results of Experiment 1 highlight the importance of sufficiently large samples in order to draw valid conclusions. The results from Experiment 2 do provide some unique insights into temporal binding in MTS, but due to a small sample we cannot reliably draw any conclusions. Hence future investigations could build on this study with a larger sample. As it may prove difficult to find individuals with MTS, a Bayesian approach is recommended because it indicates when sufficient data has been gathered, unlike conventional statistical method where one has to determine the sample size before beforehand.

Lastly, this study included complex stimuli and the visual stimuli were presented for a relatively long period (videos that were four seconds long). Previous studies (e.g., Parise & Spence, 2009; Ide & Hidaka, 2013) used much simpler stimuli and hence may have picked up on different mechanism which makes it difficult to compare results. To address this, future TOJ studies could incorporate simple visual stimuli such a quick presentation of a hand or object on a screen (without touch) paired with a tactile stimulus on the participant's hand. This would provide insight into whether stimulus complexity modulates effects of visuo-tactile temporal binding.

4.6 Conclusions

In this study I investigated the effects of visual body-ownership cues on visuo-tactile temporal processing. Using a TOJ task, I measured the difference in JNDs between viewing an egocentric hand and a sponge (to test for object form) and between viewing an egocentric hand and an allocentric hand (to test for hand orientation). Neither non-synaesthetes nor MTS showed differences in JNDs for either of the comparisons, which indicates that visual body-ownership cues do not modulate visuo-tactile temporal perception. The current study, supported by sequential analyses of the Bayes factor, suggests that previously reported effects might be unreliable due to small samples. Interestingly, the observed larger JND results for two of the three MTS for all three conditions might suggest that visuo-tactile temporal binding is stronger in these individuals, both when observing touch to a human hand and touch to an object.

My findings add to our current understanding of the cognitive mechanism underlying body perception. Based on studies with the RHI or a visuo-tactile crossmodal congruency paradigm, it appears that the unity assumption can modulate integration of multisensory signals in the spatial domain (Pavani et al., 2000; Zopf et al., 2010). However, the current findings converge on the findings by Keys et al. (2018) and provide compelling evidence that in own-body contexts, the effects of the unity assumption on multisensory integration do not extend to the temporal domain. This can potentially also explain previous reports that visual cues plausible for one's body do not enhance visuo-proprioceptive temporal binding (Hoover & Harris, 2012, 2015; Zopf et al., 2015). Future studies are needed to improve our understanding of how spatial and temporal information might be processed differently in own-body contexts.

This thesis also highlight potential directions for future studies into the underlying causes of synaesthesia. Investigating whether visuo-tactile temporal binding is generally stronger in MTS compared to non-synaesthetes (both for touch to humans and objects), will provide important insight into the underlying mechanisms of MTS and synaesthesia more broadly. This in turn can help inform current models of multisensory perception.

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Appendices

Appendix A - OSF study preregistration

Title

The effect of observing touch to a human hand on visuo-tactile temporal order judgement

Authors

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Research Questions

For context, a short introduction to this study's research questions appears in the last section of this document.

1. Does the visual presentation of touch to a human hand modulate the precision of visuo-tactile temporal order judgements?
2. Is this effect different when participants view the touched hand in an egocentric (self-specifying) compared to allocentric (other-specifying) orientation?

Hypotheses

We have two main test hypotheses:

Hypothesis for RQ1: The just-noticeable difference for visuo-tactile temporal order judgments is different when viewing a human hand being touched compared to viewing a non-corporeal object being touched.

Hypothesis for RQ2: The just-noticeable difference for visuo-tactile temporal order judgments is different when viewing the touched hand in an egocentric orientation compared to an allocentric orientation.

Sampling Plan

Existing data

Registration prior to creation of data: As of the date of submission of this research plan for preregistration, the data have not yet been collected, created, or realised.

Explanation of existing data

N/A

Data collection procedures

Participants

We will recruit right-handed undergraduate students from Macquarie University, with normal or corrected-to-normal vision. Individuals will receive course credit or 15 AUD/hour for participation. Recruitment and data collection will happen between May and October 2018.

Testing

— Participants will perform a standard visuo-tactile temporal order judgment (TOJ) on each trial. There will be 20 trials for each of the 14 SOAs resulting in 840 trials in total.

— The trials for the three conditions and SOAs are randomly intermingled

— Except for each condition's specific manipulations, all parameters for the TOJ task are kept constant between experimental conditions.

Experimental conditions

— hand in egocentric orientation (self-specifying cue)

— hand in allocentric orientation (other-specifying cue)

— sponge (control condition)

Task details

— Conditions consist of a series of trials. In each trial, participants will perform a visuo-tactile TOJ.

— Trials present two stimuli (one visual, one tactile).
— The temporal gap between the two stimuli varies in duration across trials. Either stimulus is equally likely to appear first.
— Following stimulus presentation, participants judge which of the two stimuli appeared first (by pressing a response key with their left hand. The response keys will be counterbalanced between participants).
— A new trial begins 800~1200 ms after participant response (inter-trial timing is jittered to reduce noise from oscillations of perceptual sensitivity).
— We have randomly varied the start frame of the video on each trial (with up to 6 frames) so that the seen touch on the screen always occurs at slightly different times. This will reduce expectancy effects.
— After finishing the TOJ task, participants will fill out a short empathy questionnaire (Muncer & Ling, 2006), a synaesthesia questionnaire and a mirror-touch synaesthesia questionnaire.

Stimuli & apparatus

— TOJ task. Visual stimulus will be a video showing touch to a human hand in egocentric orientation, a human hand in allocentric orientation or a sponge. The tactile stimulus will be a 30ms pulse of a vibrotactile stimulator applied to back of the participants' right hand, just below the junction between the hand and the middle finger (the metacarpophalangeal joint). We will place a printed image of the video next to the participants' hand to match the location of the tactor as closely as possible. A Dancer Design TactAmp 4.2 will control the delivery of the vibrotactile stimulator. For programming/experimental control we use Matlab/Psychtoolbox.

Sample size

We will initially test a group of 15 participants before calculating the Bayes Factor to check if our data are sensitive enough to favour one hypothesis over another. This is based on previous studies that found significant effects and medium to large effect sizes for the effect of viewing a hand on multisensory temporal perception (Ide and Hidaka., 2013; Keys et al., 2018; Hoover and Harris., 2012, 2015; Zopf et al., 2015). These studies all had sample sizes between 10 and 12 participants.

Conventional cut-offs for the interpretation of Bayes factors are typically B > 3 which means that there exists sufficient evidence for H1 rather than H0 and B < 1/3 which means that there exists sufficient evidence for H0 rather than H1. Anything in between is taken to indicate insufficient evidence (Dienes 2016). However, in order to obtain *strong* evidence, a Bayes factor of >10 or <1/10 is required (Jeffreys, 1998; Rouder et al. 2009). Our aim is to collect strong evidence and hence to keep testing until we reach a Bayes factor of >10 or <1/10. However, we might be limited due to time restrictions and in that case will conclude that we have gathered sufficient evidence if the Bayes factor is >3 or <1/3.

Sample size rationale

Employing a Bayes factor means we do not have a set sample size.

Stopping rule

If a Bayes Factor is smaller than 10:1 we plan to use an optional stopping rule (Dienes, 2016) and continue data collection until the Bayes Factor is either larger than 10 or smaller than 1/10. Alternatively we will stop data collection due to time restrictions.

Variables

Manipulated variables

We will experimentally manipulate 3 variables:

Object: The object that is presented in the videos. Two levels: (1) the visual presentation of touch to a human hand in an egocentric orientation; (2) the visual presentation of touch to a sponge that resembles a human hand in colour, size and texture but not shape.

Orientation: The orientation of the 2 hands in the video. Two levels: (1) in the egocentric orientation, the observed hand's fingers point away from the participant’s trunk, i.e., in the same orientation as their (hidden) right hand; (2) in the allocentric orientation, the observed hand’s fingers are rotated 180° (i.e., fingers pointing towards the participant's trunk).

SOAs: Stimulus onset asynchrony (SOA) for visuo-tactile stimuli in TOJ task. The temporal gap between the visual and tactile touch events varies in duration across trials. We will use 14 SOAs, ± 33, ± 67, ± 100, ± 133, ± 167 ± 200 ± 333ms; positive SOAs mean a trial where the visual stimulus was presented first.

Measured variables

Temporal order judgment task response. After each trial, participants indicate whether the visual stimulus or tactile stimulus appeared first (binary).

Indices

Measured variables that are indices are defined as follows:

Proportion of visual-first responses. We will calculate the proportion of visual first responses for each SOA in each condition. For a given SOA & condition, 1 = 100% 'visual-first' responses, and 0 = 100% 'tactile-first' responses.

Psychometric function. To model the probability of participant responses for a given SOA, we will fit sigmoid functions to the proportion of visual-first responses for each individual participant, and for each of the 3 conditions. See Analysis plan section for detail on curve fitting.

Just-noticeable difference (JND). We will calculate individual participants' JNDs (one for each of 3 conditions) from the fitted psychometric functions, using the formula:
JND = (75% threshold -- 25% threshold)/2

Design Plan

Study type

Experiment.

Blinding

No blinding is involved in this study:

Study design

Each participant will complete all conditions. Researchers analysing the experiment will be aware of the experimental conditions and research questions.

Randomisation

— SOAs and conditions will be randomised on each trial.

Analysis Plan

Statistical models

To calculate the Bayes factor we will perform two Bayes t-tests to test our hypotheses: (1) human hand versus object; (2) egocentric orientation versus allocentric orientation. Bayesian analysis requires us to specify the theory we are testing against the null hypothesis (i.e., the probability of different effects given the theory) (Dienes, 2014). We can specify a plausible predicted effect size P, based on previous studies. For this we take the average of the mean reported by Zopf et al. (2015) and Hoover and Harris (2015) (18ms and 22 ms respectively, providing us with a predicted effect size of 20ms). Our theory allows effects to go in either direction as the study by Ide and Hidaka (2013) found an effect of approximately 12ms in the opposite direction (see their Figure 2). However, we postulate that the first two studies found a relatively larger effect due to more ecologically valid stimuli. As our study also incorporates realistic stimuli we will set our P at 20ms in either direction. The effect size in previous studies comparing different orientations and hands with objects is roughly the same (see the effect sizes in Zopf et al. 2015 comparing a hand versus dots, 19ms [Experiment 1] and egocentric versus allocentric hand orientation, 18ms [Experiment 2]). Hence we will use the same prior for both our hypotheses and specify a normal distribution with the mean set to 0, and the standard deviation set to P and the tails to 2. We will calculate the Bayes factor via Dienes' online calculator. (http://www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference/Bayes.htm)

Transformations

Fitting psychometric functions. We will fit cumulative Gaussian distribution functions to TOJ response data using maximum likelihood estimation.

Follow-up analyses

-

Inference criteria

We will perform two Bayes t-tests comparing two conditions (egocentric orientation versus allocentric orientation and human hand versus object). We will continue data collection until the Bayes Factor is either larger than 10 or smaller than 1/10 or until we reach our time limit.

Data exclusion

— If any curve fit fails to converge on a solution for a sigmoid function for a given condition, all data for that participant will be excluded from further analysis and we will replace this participant.

— Performance outliers (defined as a JND > 3 S.D. away from group mean in any condition) will be excluded from further analysis and we will replace this participant.

Missing data

Incomplete datasets (i.e., for individual participants) will be excluded from all analyses (see data exclusion) and we will replace these participants.

Exploratory analysis

Participants will fill out a short empathy questionnaire (Muncer & Ling, 2006) to test for correlations between participants' JNDs and level of empathy. Participants will also fill out a synaesthesia and mirror-touch synaesthesia questionnaire to test if participants have a form of synaesthesia and whether this correlates with their individual JNDs. We will also calculate participant's Point of Subjective Simultaneity (PSS) to establish any bias towards the visual or tactile stimulus.

Other

Short introduction

Viewing one's hand being touched typically co-occurs with synchronous proprioceptive and tactile input whereas viewing someone else's hand being touched does not. Hence one important cue about what constitutes the self comes from the temporal coincidence of incoming multisensory information (Calvert et al. 2004; Driver and Spence. 2000). Recent studies have started to investigate how information about one's own body might in turn influence how we perceive incoming multisensory information.

Hoover and Harris (2012) demonstrated that participants were better at detecting the delays of their own finger movements in an egocentric hand orientation compared to an allocentric hand orientation. A similar study by Zopf, Friedman and Williams (2015) also found that viewing an anatomically plausible hand enhances perception of small visual-proprioceptive temporal asynchronies compared to a hand in an implausible orientation or dots organised in a sphere. These studies suggest that the brain relies on self-specifying body cues, such as form and orientation, at earlier stages of perceptual processes and that this directly influences *visuo-proprioceptive* temporal perception (Zopf et al., 2015).

Conversely, studies investigating the effects of self-cues on *visuo-tactile* temporal perception have produced seemingly contradictory results. Ide and Hidaka (2013) demonstrated that participants were less precise on a TOJ task when presented with a plausible hand image (forward hand) compared to an implausible hand image (inverted hand and arrow). This suggests that self-specifying body cues influence temporal perception but in the opposite direction. Interestingly, Keys, Rich and Zopf (2018) investigated the effects of self-specifying cues on temporal perception via a synchrony judgement (SJ) task and found strong evidence to suggest no effect.

This discrepancy in findings between the studies might be due to varying ecological validity of the stimuli. Whereas Ide and Hidaka (2013) used a line drawing of a hand, Keys et al. (2018) used a plaster hand which much more accurately resembles a real hand. However, participants in these studies knew they were not looking at a real hand, unlike the two visuo-proprioceptive studies where participants viewed a virtual hand or their own hand on a screen.

The first two studies furthermore, paired the visual stimulus with a LED light which does not in any way correspond to the applied tactile stimulus. The current study aims to close this gap by investigating the effects of more realistic self-specifying hand cues on the temporal order judgement of visuo-tactile stimuli. We will incorporate a visual touch event indicated by a stick tapping a hand (instead of the typically used flashing light), which is paired with a similar tactile tap on the participant's own hand. The broad aim of this experiment is to enhance our understanding of the cognitive processes that underlie body-ownership.

Further, as this study looks at perceptual binding of touch and vision, it may also tell us more about the underlying mechanisms of mirror-touch synaesthesia. This is a condition where observing touch to another person results in a private sensation of touch on the synaesthete's own body (Banissy et al. 2009). Parise and Spence (2009) demonstrate that synaesthetic associations can enhance perceptual binding between audio-visual stimuli in non-synaesthetes. We speculate that similar mechanisms underlie perceptual binding between visuo-tactile stimuli. Our study provides a novel way to further investigate.

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Appendix B - Questionnaires

SHORT EMPATHY QUESTIONNAIRE

A short 15-item version of the EQ questionnaire, testing cognitive empathy, social skills and emotional reactivity (Muncer & Ling, 2006). Participants indicated how much they agreed with a statement on a 4-point Likert scale, ranging from "Strongly disagree" to "Strongly agree".

Cognitive empathy	
1	I am good at predicting how someone will feel
2	I am quick to spot when someone in a group is feeling awkward or uncomfortable
3	I can sense if I am intruding, even if the other person does not tell me
4	I can tune into how someone else feels rapidly and intuitively
5	I can easily work out what another person might want to talk about
Social skills	
6	I find it difficult to explain to others things that I understand easily, when they do not understand it first time
7	I find it hard to know what to do in a social situation
8	Friendships and relationships are just too difficult, so I tend not to bother with them
9	I often find it difficult to judge if something is rude or polite
10	I do not tend to find social situations confusing
Emotional reactivity	
11	I really enjoy caring for other people
12	If I say something that someone else is offended by, I think that is their problem, not mine
13	Seeing people cry does not really upset me
14	I usually stay emotionally detached when watching a film
15	I tend to get emotionally involved with a friend's problems

SHORT SYNAESTHESIA QUESTIONNAIRE

Read the following statements about synaesthesia. All refer to a response that occurs without effort (it just happens) and tends to be the same each time. Choose the answer that fits best:

1. When I see, hear or think of letters, numbers, or words, I experience them to have:

(a) Colours	Yes/No
(b) Personalities	Yes/No
(c) Specific locations in space	Yes/No
(d) Other (please specify)	Yes/No

2. When I hear sounds I experience:

(a) Colours	Yes/No
(b) Textures	Yes/No
(c) Abstract shapes	Yes/No
(d) Other (please specify)	Yes/No

2.1 Sounds that give me visual (or other) experiences are:

(a) Music	Yes/No
(b) Ambient sounds	Yes/No
(c) Voices	Yes/No
(d) Other (please specify)	Yes/No

3. When I see someone else being touched, I experience touch myself

Yes/No

4. Are there any other types of synaesthesia you think you may have? Please indicate any other synaesthetic experiences in the notes column.

Type of Synaesthesia	Y	N	Maybe	Details/notes
Coloured weekdays				
Coloured months of the year				
Coloured music notes (written)				
Coloured smell				
Coloured taste				
Coloured touch				
Coloured temperature				
Coloured pain				
Coloured personalities/people/auras				
Faces > Colour/smell/taste				
Emotion > Smell /Taste				
Emotion > Taste				
Emotion > Colour/other visual				
Events> Smell/tastes/sounds				
Flashes of light > Sound/Feeling				
Objects > Personality				
Sound > Taste				
Sound > Smell				
Sound > Touch				
Smell > Sound				
Smell > Touch/Temperature				
Smell > Colour				
Taste > Sound				
Taste > Touch/Temperature				

Textures > Sound/Feelings				
Touch > Sound				
Touch > Taste/Smell				
Temperature > Sound				
Temperature > Taste/Smell				
Vision (static) > Sound				
Visual motion > Sound				
Vision > smell				
Vision > taste				
Vision > touch/temperature				
Personalities/people > smell				
Personalities/people > taste				
Places > Smell/Tastes/Sounds				

Appendix C - Interview transcripts Experiment 2

Participant 1, rated as MTS

When she sees someone else being touched, it is more a feeling of being touched, she wouldn’t really say it’s a tingling. She doesn’t know if there there's a word for the sensation but it is that soft pressure/rubbing/brushing feeling when being touched. Most of the time it can be very faint, but noticeable. If the scene is quite emotional, she can "feel" it quite intensely. For example if she sees people hugging she can "feel the warmth and emotions" that she would experience when being hugged. Sometimes she also actually feels slight warmth. She experiences these sensations on the same side of her body as where the touch is happening to the other person. It is more of a general “touched” feeling in that area. It is the same when seeing different people being touched, like friends, family or strangers. If a friend is telling her how they felt in a certain situation she would feel it too. For example, if they were in a situation where they felt uncomfortable she get chills and shudders. But seeing as strangers may not be as open with telling her such things, she’s not sure if it would have the same result. She also feels other people’s pain and experiences this as sharp and pointed and in comparison it feels much colder. She experiences these sensations regularly. She doesn’t remember if she had it much as a child but it has definitely been present during adulthood. These experiences do not affect her positively or negatively in any way. She’s quite indifferently to it but supposes it might be positive in the sense of empathy, understanding and being "in tune" with others. She doesn’t have any other types of synaesthesia and she doesn’t think anyone else in her family has either MTS or any other types of synaesthesia. Although when people verbally describe an experience, like if they had a painful accident (broke their leg, getting scratched or cut, rolled ankle) or when they are describing feeling something pleasant (fresh bed linen or if they’re talking about how soft and fluffy their new kitten is) she can feel faint pain/sensations in the same area or she can "feel" what they’re talking about (the fluffiness of a kitten on her hands/bed linen on her body).

After the experiment she mentioned that the when viewing a hand (mostly in the egocentric orientation but also in the allocentric orientation) the task was much harder than when viewing the sponge as it was hard to distinguish the touch. Because of this, she was much more focused on the touch on her hand as opposed to the touch on the screen.

Ward questionnaire

She answered yes to feeling touch on 12 out of the 14 videos (touch without pain).

Intensity on a scale to 10 = 3.3

6 mirrored and 6 anatomical (according to the Ward screener she'd be considered inconsistent).

Participant 2, rated as MTS

When seeing touch she has a general feeling in the same area that is being touched. She is always very much aware of the feeling and it happens often. Some parts of the body elicit more of a response than others (for example the face is a much stronger feeling than the arm). She usually feels it on the right side of her body, regardless of where she sees the touch (left or right side and from a first or third person perspective). Some parts of the body give her a tingling sensation, similar to having the hairs on your arm rise. Whenever she observes touch (especially to the face) she has an image in her head of it being her that is being touched. Depending on the kind of touch it could either be a more general or localised feeling. If it's for example brushing of a less salient limb such as the arm, it feels a bit more general, whereas if it is touch to a face it feels very specific. She gets these experiences both when watching touch in real life and in movies, but not with objects being touched. If the person being touched is someone she likes/dislikes or if there is something specific about the person that stands out either negatively or positively, it is much more noticeable. It is also more or less pleasurable when she likes or dislikes someone. She also feels pain when she sees people in pain on tv or in real life and finds it very painful, as if she can really feel it on her body. If someone's arm gets stabbed she can feel it, so she finds it very uncomfortable to watch violent tv shows. These experiences are more intense when she focuses on the touch, the imagery in her head becomes more intense. It also depends on her mood, when she's in a bad mood she doesn't notice it as much but when she's in a good mood she is more aware of it. She has experienced this constantly but is sometimes more or less aware of it. It used to be very intense as a child and even with objects that she had an attachment too, like her plush toys but not with general objects. Now it’s a bit less and only with people (but now it remains constant). These experiences affect her mostly positively as she feels she is a very empathetic person, but sometimes other people’s emotions can be very overwhelming. When it comes to touch it is mostly positive. She reports having misophonia where she experiences negative reaction to sounds and smells. She really hates the sounds of the vacuum cleaner, hearing it in the morning makes her depressed for the rest of the day. She strongly dislikes sounds of heaters and washing machines. She likes the sound of the wind, with makes her feel really good physically and relaxed. But she doesn’t like it when there is no wind, quiet makes her feel really tense. Sounds and smells lead to a similar experience but these can be more extreme and good or bad, which makes it a more intense experience than seeing / feeling touch. She constantly associates smells/sounds with objects or feelings, for example a location can make her think of sweat and it would be so uncomfortable that she would have to move as she cannot be in the space, this is often very overwhelming. Based on the short synaesthesia questionnaire, she mentions that, especially as a child, letters elicit colours and numbers have personalities (she associates the number 7 with dark purple, really likes the number 6 but dislikes the number 8). She mentions she generally really doesn’t like numbers and is bad at math. Does not have this much with words, just prefers some words over others. These associations have stayed the same overtime. Sounds elicit “swells of colours”. She associates the sound of candles with violet for example. When it is silent she sees a “really gross pattern in her head” which feels like what looking at clusters of shapes feel like. Listening to music generally leads to these experiences which she feels she cannot control, it just happens, but she can tune out a little if she tries. She’s so used to it that she doesn’t really mind, it was more intense when she was young. She very often associates very specific sounds with scenarios (events that could happen or have happened but can play out differently, made up places, being someone/something completely different herself). Music, ambient sounds and voices elicit these experiences. She experiences colours when tasting particular things but not as much as with words. Things that taste good have certain colours, cheese is orange (vague vision but not very intrusive), lasagne is red, she finds white chocolate with popping candy disgusting and this looks like a dark black. She clusters people together who “belong to the same colour”. People with dark hair and pale skin are blue and these people get clustered together. She sees this inside of her head, not outside. Vaguely associates smells with colours but not as strong. People and places have strong smells. Most strongly experiences smells and sounds and grapheme-personalities. Her brother also has some similar experiences, sounds elicit negative emotions, but not with touch. No one in her family has synaesthesia.

During experiment she strongly noticed the difference between object and hands. When seeing the skin being touched it evoked a reaction but not with the object. She actually felt the observed touch on her own hand, “that is why a lot of the time I couldn’t tell whether the viewed tap and the actual tap were at the same time”. The ego and allocentric hand seemed the same. Seeing the indentation of the sticker on the hand was very distracting. She had a strategy most of the time and she associated the touch with a rhythm in her head and that is how she’d know whether the tap was before the seen touch. When the rhythm sounded “off” she’d know it was the other way around.

Ward questionnaire

Answered yes to feeling touch on 11 out of the 14 videos (touch without pain)
Intensity on a scale to 10 = 4.5
4 mirrored, 7 anatomical (according to the Ward screener she’d be considered anatomical)

Participant 3, rated as MTS

What she feels when seeing touch depends on the context. The knife in the Ward screener felt like a tinging, poking sensation. But if people are holding hands she can feel a warm feeling. It’s more intense when she sees someone in pain as this creates an empathetic reaction where she can feel the pain on her body, this does not feel like touch. If she watches a movie and sees someone get stabbed in the hand her hand hurts, it’s a bit of a disgusting and uneasy feeling. She consistently experiences touch on the mirrored side. Depending on the action it can feel localised or general. Holding hands would be more general but being touched by a knife would be more localised. The feeling depends on the person, if it is a complete stranger she would still feel pain but the warm feelings are only with close people such as family members. If she focuses intensely on the touch she could feel it with everyone. The pain experiences happen quite often, whenever she sees someone in pain but the touch is generally not as often. The pain experience stands out much more. When she was doing the MTS screener, she was focused more on the touch and could feel it but normally she's not so aware of it. She thinks she had the same experiences her whole life but hasn't paid that much attention to it until now. Experiences are the same when watching a movie and in real life. The experience does depend on whether she's paying attention to it but does not depend on mood. Her sister has audio-visual synaesthesia (sees colours when playing piano) but no reports of mirror-touch in the family. She associates some sounds with colours, like a C-chord with blue and an A-chord with yellow, this is only with the piano and no other sounds, although she mentioned this might be a bit more of a feeling. She associates major chords on the piano with happy feelings and minor chords with unhappy feelings. She maybe has a vague association of colour when seeing someone in pain. She associates colours with vibes she gets off people, yellow is more of a happy vibe and purple is more angry, but this is more of a vague feeling. She maybe sees some flashes of light when listening to a beat but not with anything else.

During the computer tasks she thought the hand on the screen felt like her own hand. When she saw the tap on the screen she would feel it on her own hand, it was a vague feeling but it was there and made it a bit confusing. This was stronger for the egocentric hand and a little for the allocentric hand. She did not feel much when viewing the object. She did not have a strategy but she was more focused on her own hand and whether or not she felt it there first.

Ward questionnaire

Answered yes to feeling touch on 6 out of the 14 videos (touch without pain, touch with pain and feeling pricked by a needle).

Intensity on a scale to 10 = 2.7

4 mirrored and 2 anatomical (according to the Ward screener she'd be considered mirrored).

Participant not rated as MTS

"When I watched the videos I didn't have much response because it didn't feel personal, it felt like a disconnect". She didn't feel any response to the videos in the MTS screener, the scratching for example felt a bit more like a general feeling over her back and neck. In real life, if it's more personal she feels it as tingling in her finger tips. When she feels worked up, or she is in a crowd for example, she feels like she is being touched, even when they are far away, like a tingling up her spine, like she is being shocked. Seeing touch results in a general tingling feeling, sometimes a slight pressure but sometimes when seeing a hand being touched, it feels like fingerprints on her hand. However, more often it feels like a general tingling feeling. Occasionally she feels something when the other person's right side is being touched, she feels this predominantly on her left side. She feels it more when she knows them, as it feels more personal and it is more relatable. When she sees friends touching each other she feels it more. It's almost like a memory coming back when they touched her. She only feels something with strangers when she feels stressed. When it's a bad person it's a negative feeling, like an electric shock down her spine. This is the same with sounds she dislikes. There are certain areas of the body she particularly dislikes, like seeing feet being touched is a gross feeling. When she sees someone pulling their nails she can feel it in her hands and when it is something with teeth she can feel it in her gums. When she's stressed, seeing pain feels like a phantom sensation of the pain on her body, like she can empathise with it, especially with nails and feet which she hates so she feels that a lot. The videos from the MTS screener did not feel as strong, but when she watches a movie and becomes more attached to a character she would feel it more. Even when she's reading she can feel the tingling sensation down her spine, but only when describing a painful scenario, not when reading about touches. It is more intense when she is in a negative mood, she gets touch averse, especially in public transport it is intense. She is not constantly aware of these experiences. Only when she received my email with questions she thought about it and realised she recognised these general experiences. As she didn't really think about it until now she hasn't really considered whether she normally experiences this. She is more used to the tingling feeling down her spine, which often feels really nice when she sees pleasant touch. She was surprised to find out that not everyone feels this tingling feeling, like a cracked egg on her head running down her spine. The touch experience is generally positive as she feels more connected to her friends. She says she thinks she has autonomous sensory meridian response. She also mentions that sensations in her mouth are specifically intense. When she thinks of crusty bread being eaten she feels the weight in her mouth or when an apple is being eaten she can feel that against her teeth. The feeling is always related to the food being eaten. She associates a few numbers with experiences, for example the number 4 seems lucky because she used to swim in lane number 4 as a kid and she likes number 8 because it's her birthday, but she says it is specifically related to memory. Loud sounds remind her of nails over an old carpet/chalk board without the high pitch and leads to tingling sensation and pain. This is both for music and other sounds like a dog barking. As long as it's loud and abrupt, it feels like something has been turned on in her like a flash and it gives her the tingling sensation. Some sounds make her feel nice, like a car being turned on. When she's startled, it feels like cotton in her mouth, almost painful. When she's anxious she has a really sensitive mouth and cannot eat anything. Sounds can make her feel nauseous, almost like she's full and she cannot eat anything. People, emotions and situations evoke a feeling in her mouth.

She only realised half way through the computer task that one hand was upside down, which she says did not matter to her. When seeing touch on the hand she did not feel anything on her own hand. She mentioned she heard a sound in her head, one associated with the hand on the screen and one with her own hand, that is how she knew which one came first.

Ward questionnaire

Answered yes to feeling touch on 2 out of the 14 videos (touch without pain)

Intensity on a scale to 10 = 1.5

1 mirrored, 1 anatomical (according to the Ward screener she'd be considered inconsistent)

Participant not rated as MTS

When she sees touch she can sort of feel it in her throat area, and she can see it in her mind. If she sees someone being touched on the arm, she can't literally feel it on her arm as it's a different feeling, she knows it's not really there. It feels like when the wind blows at you she says, it feels like pressure, no tingling. She asked whether other mirror-touch synaesthetes actually feel touch when they see touch because she cannot actually feel it. “I don't think I have that”. It wasn't there as a child, she said she was really “normal growing up”. During high school she started to want to know what people feel because she was quite lonely, so she started to try and feel what others feel and hence developed it. As a child this wasn't obvious at all, she felt pretty normal. She says she can't watch Game of Thrones because it's too gory but she cannot feel it herself on her body. When she sees touch on my right arm, she has an idea of her right hand being touched. It is different when watching a movie because this is more intense than real life. She feels that it is more obvious on TV because the camera is focused on it and because of the background sounds. It is less pronounced on a sad day, in that case she could easily watch a gory movie. She only notices it when she thinks about it and focuses on it, in normal life she doesn't really notice it. The experience of touch is something that is on or off on some days, it depends on whether she wants to feel it. She doesn't feel like she is born with this but developed it herself. She hasn't really thought about whether it is different with different people such as strangers/close people. In her idea it might be stronger with people she is closer with, but she's not entirely sure, it seems like it's just the same for different people. She doesn't have these experiences when seeing someone in pain. It might be a bit of an uncomfortable feeling but it is more an empathetic experience. She does have one instance where she associated a sharp red accompanied by high pitch with this one smell in the elevator from her childhood. She does not have this with anything else, only things related to memory. In regards whether these experiences affect her positively or negatively in any way she answered that when she first realised she could understand other people's touch she liked it, cause she likes being different from other people. In terms of other types of synaesthesia, she says she measures time by distance, for example 45 minutes is that much time (holds hands apart). Only when she really thinks about it she might associate some colours with music. She has no family members with synaesthesia. Sometimes she sees a wavelength shape and a colour when listening to particular sounds. When it's a new sound it's a bit more sharp but then when she listens to it more often, the colours start to fade as she gets used to it. She says she sees a coloured shape in her head when she experiences pain. She only started having all these experiences since high school when she started to pay attention to it. She usually sees a white light flash when she hears a sound, but when I put the metal bottle on the table she said it sounded like red, but only when she focused on it.

She said she heard two sounds in her head during the experiment, related to the tap. Comparing the three conditions, she didn't experience these differently. She didn't notice whether it was a hand or object much because she focuses on the dot. Seeing the object being touched made her think of soap being touched. She didn't feel the tap on her own hand when seeing the touch on the hands during the experiment. It was not a sensation but more a general “knowledge” that the hand was being touched.

Ward questionnaire

Answered yes to feeling touch on 14 out of the 14 videos (touch without pain).
Intensity on a scale to 10 = 3.9
For the first 7 touch videos she responded with saying that the touch was “not localisable” and then answered with 4 mirrored and 3 anatomical for the remaining 7 (according to the Ward screener she’d be considered inconsistent).

Participant not rated as MTS

*It was difficult to get clear answers to my questions as she was often diverting to talking about levels of consciousness and being able to take over people’s pain, but did not say much about feeling touch when seeing touch. She seemed to want to talk more about being empathetic and emotional, and reported being a medium.

Seeing touch makes her anticipate other people’s emotions. She is a nurse and would empathise with other people’s pain. Her mother and husband have chronic pain in the shoulder and she could feel it as well from a distance (while not being in the same room). She only feels others people’s touch when there is a point to it. She can turn it on or off, and she can step back from it, there is a level of control. She can feel something if she likes it and when she is turning it on. She says she can feel other people’s emphysema for example. She mirrors other people’s body language. The seen/felt touch might be mirrored but this is not very pronounced. She says she doesn’t understand “the levels” of it and that there are different levels of reality. The feeling has changed over life and in her first month of nursing, someone told her to be more aware of other people’s feelings and that was a profound thing that changed her. She thinks her family members all have strong senses but not synaesthesia.

She thought that watching the knife in the Ward questionnaire had something sensuous about it and it wasn't uncomfortable. During the computer task she thought the taps were musical, and she was listening to a rhythm and whether it changed or not. But she could not feel the touch when viewing touch.

Ward questionnaire

Answered yes to feeling touch on 8 out of the 14 videos (touch without pain, pressure).
Intensity on a scale to 10 = 1.9
4 mirrored and 4 anatomical (according to the Ward screener she'd be considered inconsistent).

Participant not rated as MTS

Seeing someone being touched leads to a tingling feeling under the skin, usually where the other person is being touched. This sometimes happen but not always. Seeing the knife on the face in the MTS screener led to a strong tingling feeling which is mirrored or random. This is either in the same spot on the opposite side, or on a random spot on his body. When he saw the guy itching his shoulder he felt itching all over his arm. But it does not feel like touch at all when he sees touch. It is a weird, uncomfortable tingling feeling. Especially with pain or when he saw that knife in the video. This makes the hairs on the back of his neck stand up. It goes from his head down his spine. He says he feels this when seeing someone else in pain. It is a similar feeling to when he sees someone eating with wooden cutlery, this creates shivers down his spine. The feeling is much more intense with people he cares about and loves and he does not feel it with people he dislikes. Pain is a different experience from touch. He doesn't feel pain in the same way as the person experiencing pain does. For example a needle doesn't feel like stabbing but more like a bruise or pressure. When someone is sick he feels sick as well. He gets a headache when his mum tells him she has a head ache. He has these experiences all the time, especially with being sick. Tingling is only specific to people he cares about and weird feelings like metal or wood with cutlery. He experiences a lot of sympathetic pain. These experiences most often affect him negatively, especially the pain/being unwell. Tingling he doesn't mind cause it is fun to feel. Nails on a chalk board or "wrong" music chords also gives him tingles down his spine. This could be with bad or good sounds. As a child (not anymore) he would kind of see colour with music but this is much more of an association like picturing a person when they're talking on the radio. As a child he used to think that foods and smells were coloured, so carrots taste orange but it's usually the same colour as the food. But then there is one case, matcha green ice cream, which does not seem green. He thinks it is an association more than anything, he doesn't actually see it. He associates pain with red but doesn't know why. That is the only pain-colour association. He says he associates smells with temperature, like smelling it is a warm day when he goes outside. As a child he would write: "today smells warm". He associates smells with people but these are just associations again. A friend used to live in a very sterile house so he would smell sterile. His sister experiences the tingling feeling as well. No one else in his family has synaesthesia.

During the computer task he had the same experiences for the sponge as for both the hands. He did not realise the hand was upside down until half way through. He mentioned that the experiment felt bizarre but this was not because he could feel touch when viewing the touch on the screen.

Ward questionnaire

He never answered yes to any of the touch videos.

Ward Screener Criteria

- For identifying MTS we were only interested in tactile sensations and the following answers were considered as "touch": touch (without pain), painful touch, the feeling of being scratched and "other" responses that described touch (e.g., "pressure" being the most common term). Tingling and itchiness are not regarded as "touch".
- 14 out of 24 videos depict touch to a human.
- If the participant answers that he or she experiences touch to at least 7 "human touch videos" this would qualify as MTS.
- The average self-reported intensity of the felt touch of people with MTS is 3.4 out of 10.
- The laterality of the response to each video was coded as anatomical or specular. From this, each participant was classified as having a specular mapping, anatomical mapping, or an inconsistent mapping. The latter occurred if they produced an approximately equal number of anatomical and specular responses (differing by <2).
- MTS usually experience touch in a localised spot (e.g., the same limb) and it is not a general feeling all over their body.

Appendix D - Ethics approval

Office of the Deputy Vice-Chancellor
(Research)

Research Office
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31 May 2017

Dear Associate Professor Rich

Reference No: 5201700508

Title: *Investigating cognitive mechanisms underlying visual, auditory, body-related information processing and sensorimotor learning*

Thank you for submitting the above application for ethical and scientific review. Your application was considered by the Macquarie University Human Research Ethics Committee (HREC (Medical Sciences)).

I am pleased to advise that ethical and scientific approval has been granted for this project to be conducted at:

- Macquarie University

This research meets the requirements set out in the *National Statement on Ethical Conduct in Human Research* (2007 – Updated May 2015) (the *National Statement*).

Standard Conditions of Approval:

1. Continuing compliance with the requirements of the *National Statement,* which is available at the following website:

http://www.nhmrc.gov.au/book/national-statement-ethical-conduct-human-research

2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol.

3. All adverse events, including events which might affect the continued ethical and scientific acceptability of the project, must be reported to the HREC within 72 hours.

4. Proposed changes to the protocol and associated documents must be submitted to the Committee for approval before implementation.

It is the responsibility of the Chief investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the Ethics Secretariat on 9850 4194 or by email ethics.secretariat@mq.edu.au

The HREC (Medical Sciences) Terms of Reference and Standard Operating Procedures are available from the Research Office website at:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics

The HREC (Medical Sciences) wishes you every success in your research.

Yours sincerely

Professor Tony Eyers
Chair, Macquarie University Human Research Ethics Committee (Medical Sciences)

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research* (2007) and the *CPMP/ICH Note for Guidance on Good Clinical Practice*.

Details of this approval are as follows:

Approval Date: 25 May 2017

The following documentation has been reviewed and approved by the HREC (Medical Sciences):

Documents reviewed	Version no.	Date
Macquarie University Ethics Application Form		Received 09 May 2017
Macquarie Participant Information and Consent Form (PICF)	1.0*	09 May 2017
Participant Questionnaires including: - Demographics and Handedness Questionnaire - Video Game Playing Questionnaire – Past Year - Past experience – Not including this past year - Rubber Hand Illusion questionnaire	1.0*	09 May 2017

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