

Multisensory temporal processing in own-body contexts:
Do bodily-self cues affect visual-tactile temporal perception?

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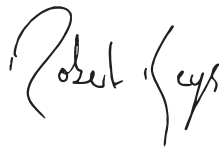
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Author's statement

I certify that this thesis is entirely my own work 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 for formal assessment in any other course or institution. The Human Research Ethics Committee of Macquarie University approved this project (Reference No: 5201200558).

A handwritten signature in black ink, appearing to read "Robert Gey". The signature is fluid and cursive, with the first name "Robert" and the last name "Gey" clearly distinguishable.

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Summary

In this thesis, I investigated interactions between own-body contexts and visual-tactile temporal processing. Previous findings show that bodily-self cues, indicating that seen body parts are plausibly part of one's own body, alter the perception of visual-proprioceptive synchrony perception. An interpretation of these findings predicts that other common multisensory combinations associated with own-body contexts, such as visual-tactile events, would be similarly affected by bodily-self cues.

In two experiments, I measured the difference in detection of visual-tactile asynchrony between plausible and implausible bodily-self cues. I found no difference in precision of visual-tactile asynchrony detection between plausible and implausible bodily-self contexts in either experiment.

In contrast, Bayesian analyses of the current findings provide compelling evidence that bodily-self cues do not increase the precision of visual-tactile asynchrony detection. Rather, these findings suggest that visual-proprioceptive synchrony perception in own-body contexts is a special case of dynamic multisensory processing.

The current findings have implications for the direction of future research into own-body perception, and a better understanding of the cognitive processes that underlie multisensory perception in own-body contexts.

1 Introduction

The body is the locus of all environment-oriented action and perception. To interact with one's environment, it is necessary to accurately distinguish one's own body from other stimuli (Maravita, Spence, & Driver, 2003; Zopf, Savage, & Williams, 2010). Further, for a representation of the body to be useful in guiding action, the body's form, spatial orientation, and environment-relative position must be represented (Graziano & Botvinick, 2002).

Representing the body is a complex problem for the cognitive system. This is due in part to the various ways of perceiving one's own body. Cues indicating one's own body are *bodily-self* cues, and can come from a variety of sensory and cognitive inputs. Information about the body's posture or form can be found in all sensory modalities. Proprioceptive, visual, vestibular, and tactile inputs all contain information the brain may use to represent the body (Spence, 2015). Stimuli associated with the body are also dynamic: the body itself will change drastically over one's lifetime through development, growth, and ageing. The body even changes in shorter timescales: complex postural changes occur from moment to moment as we interact with our environments. The mechanism for representing the body must be able to update in light of morphological and postural change.

Research into multisensory body perception is essential for our understanding of the cognitive processes that integrate information across modalities in own-body contexts. Explanations of these processes are essential for understanding body perception and how it can be disturbed in clinical populations. For example, research in body representation has revealed critical changes to body representations in both schizophrenia (Franck et al., 2001) and autism spectrum disorders (Paton, Hohwy, & Enticott, 2012). A better understanding of the cognitive and neural mechanisms underlying body representation has potential implications for diagnosis and treatment of such disorders.

In this thesis, I examine a particular aspect of body representation and the way it interacts with multisensory perception. In this initial chapter, I discuss the literature relevant to this research. First, I review the types of cues we have about our bodies, how the information from these cues might be combined, and the methodologies used to study bodily-self perception. I then introduce and describe the research questions this study addresses. In Chapters 2 and 3, I present two experiments to investigate the interaction between bodily-self cues and visual-tactile processing, and discuss the results and implications of this study in Chapter 4.

1.1 Multisensory cues for the bodily-self

Different sense modalities give different sorts of temporal and spatial information about the body. Given the importance of representing the body, the various channels of body-information must be combined in a coherent fashion. Research from diverse areas in the cognitive and neural sciences has converged on the idea that cognitive representations of the body are multisensory constructs (Ehrsson, 2012; Graziano & Botvinick, 2002; Makin, Holmes, & Ehrsson, 2008; Spence, 2015; Tsakiris, 2010). In the following section, I review evidence supporting this view—that is, that representing the body involves the combination of multisensory bodily-self cues. Further, I discuss methodological approaches for the investigation of multisensory processing in own-body contexts.

Although we can consciously recognise our bodily-selves in various ways, subjective experience does not clarify which signals the brain requires to represent the body, or how the signals might be used. In conscious experience, we can direct attention to various perceptual presentations of the bodily-self.¹ However, in many complex tasks, attention is directed at the environment. Despite a lack of overt monitoring, the brain is able to sensibly organise information from multiple inputs, and keep track of the body’s movement and location.

The brain needs to represent both bodily-form and posture. This information comes from multiple sensory signals. First, proprioceptive receptors in muscles,

¹A terminological note: This thesis avoids using the philosophically-loaded term *self* to refer to the body of a cognitive agent, including when other researchers use this term in this sense, i.e., the self-as-body. Following Longo, Cardozo, and Haggard (2008) and Noel, Pfeiffer, Blanke, and Serino (2015), I use the term *bodily-self* in strict reference to certain physical parts (organic or non-body) for which a cognitive agent has a sense (conscious or non-conscious) of embodiment or ownership. I make no comment on the entirely separate issue of the psychological or emotional self, and eschew metaphysical claims about personal identity.

joints, and skin give the relative positions of movable body parts. From these inputs, the brain is informed of the overall body posture. Proprioception, however, is not the only sense that reveals posture: postural representations incorporate a much richer selection of informational input (Graziano & Botvinick, 2002; Spence, 2015; Tsakiris, 2010). This can include visual impressions of the body, vestibular information, and also touch. For example, seeing your arm on your desk gives information regarding arm position. Although proprioceptive postural representations could make visual information about posture redundant, the coherency of these two information streams allows for a stronger ‘hypothesis’ about the actual location of the body: simultaneously processing information from multiple channels provides a means for determining the accuracy of individual sensory inputs, and helps minimise sensory-specific distortions.

Vision is also revealing of bodily *form*. From the retinal image, one can visually recognise one’s own body. A lifetime of visual experiences associated with one’s own body allows for a precise model of the visual form of the body. However, our experiences are not typically of a static body. In viewing the body during action, the brain has further information that can aid in the visual distinction of the body from the environment. Information about executed actions—motor efference—allows the brain to predict particular sensory consequences. If a visual impression of an acting body matches the sensorimotor expectation generated when an action is performed, the brain has good evidence that the body belongs to the agent (Apps & Tsakiris, 2014). Likewise, a mismatch between visual experience and sensory expectations is evidence that the body seen is not the bodily-self.

Another potential bodily-self cue is the temporal synchrony of multisensory inputs (Kilteni, Maselli, Kording, & Slater, 2015; Tsakiris & Haggard, 2005). Tactile sensations may be localised using information from receptors on the skin: we are able to approximate the location of a touch without looking. Sensations on the skin can also be visually localised: if an insect is to crawl across your finger, you can both feel and see where you are being touched. When looking at the source of a tactile stimulus, the visual and tactile sensations are temporally aligned. Such temporal alignment is evidence that the two stimuli (visual and tactile) are caused by the same event. In the case of the insect walking over one’s finger, the combination of tactile sensation, and the localisation of the tactile sensation *on that finger* gives evidence that the seen body part belongs to the bodily-self.

An important question, however, remains for understanding bodily-self perception: *what information is actually used by the brain to represent the body, and how might it be combined?* The complexity and the dynamic nature of the information found in bodily-self cues makes this a complicated question. Different sources of sensory information, in various contexts, can give information about either body-form or posture, potentially satisfying criteria for a useful representation of one's own body. Further, not only are there multiple senses that give information about the body, but further cues—such as temporal synchrony and spatial congruency—are gained when the senses are considered together. Given that there are multiple channels of body-information, we need to ask more precise questions about the influence of different bodily-self cues on the perception of the body, as well as how different bodily-self cues interact (Spence, 2015).

1.1.1 Manipulating and measuring bodily-self perception

To study the role of particular bodily-self cues, it is possible to make use of bodily illusion paradigms, such as the rubber hand illusion (RHI). In the RHI paradigm, a subject views a realistic looking artificial hand (typically made of rubber), while their real hand is hidden. Using a pair of brushes (or other suitable implement) an experimenter simultaneously stimulates the subject's hidden (real) hand and the rubber hand in the same fashion. After a few moments of feeling the brushing sensation and seeing the brushing of the rubber hand, many subjects begin to feel a sense of *ownership* or *embodiment* of the rubber hand. The congruency of the visual and tactile sensations seems to elicit an experience akin to the rubber hand *being a part of one's own body*. This feeling is characterised by subjective reports that the felt sensation seems to be coming from the location seen on the rubber hand, or that the rubber hand belongs to the subject (Botvinick & Cohen, 1998; de Vignemont, 2011; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; Tsakiris & Haggard, 2005). This illusion is often used as a method to study the influence of different sensory signals on own-body perception. Using the RHI, researchers can induce multisensory conflicts through experimental manipulation of body-cuing information. This research has demonstrated that visual form, visual posture, intermodal synchrony, and proprioceptive cues are important for representations of the body.

A variety of measurable phenomena can indicate changes to body represen-

tations. However, it is not clear how different measures relate, or even if they are measures of the same cognitive process. Questionnaires present a standard measure of altered body representation (Longo, Schüür, et al., 2008; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009; Tsakiris, 2010). Experiences of the RHI can also accompany changes in perceived body position (Botvinick & Cohen, 1998; Tsakiris, Carpenter, James, & Fotopoulou, 2010), an effect known as proprioceptive drift, and also representations of body position for action (Zopf, Truong, Finkbeiner, Friedman, & Williams, 2011). Manipulated proprioception associated with bodily-self cues is often used as a complementary measure of illusory embodiment or ownership. Measures of *proprioceptive drift* indicate the spatial difference in perceived location of a body part before and after perceiving bodily-self cues. Many studies report proprioceptive drift towards an object (e.g., a rubber hand) as evidence of the rubber hand illusion (Botvinick & Cohen, 1998; Costantini & Haggard, 2007; Kammers, Longo, Tsakiris, Dijkerman, & Haggard, 2009; Longo, Schüür, et al., 2008).

As an implicit, behavioural measure, proprioceptive drift has potential advantages over subjective measures, like embodiment questionnaires, which could critically depend on how participants interpret questionnaire items. However, the literature offers no clear explanation of how these two measures relate, or even if they indicate the same mechanisms (Rohde, Di Luca, & Ernst, 2011). Whereas Longo, Schüür, et al. (2008) found that feelings of ownership measured from questionnaires were significant predictors of proprioceptive drift, Holle, McLatchie, Maurer, and Ward (2011) found critical differences between the measurements, and suggested that there is a dissociation between drift and illusory ownership. When the RHI is experienced, it is argued that the artificial hand has been incorporated into the representation of the body (Tsakiris, 2010). However, it is not clear whether the rubber hand illusion is a categorical effect, or if the illusion is felt in degrees (de Vignemont, 2011). Hence, it is also not clear whether sensory cues categorically represent the bodily-self, or if there is a continuum of bodily-self evidence. Although illusory experiences might be sufficient evidence for a change in the body representation, this does not indicate that illusory ownership experiences are a necessary antecedent for changes to the body representation. Despite some conceptual concern surrounding how these measures relate, we do know that many different bodily-self cues, such as multisensory synchrony

(Tsakiris & Haggard, 2005) and orientation (Costantini & Haggard, 2007), affect both of them. Thus, either measure can offer evidence that particular bodily-self cues affect aspects of body representation.

Various modifications and measures of the rubber hand illusion paradigm demonstrate the importance of specific bodily-self cues—particularly multisensory synchrony, plausible body-part orientation, and viewed bodily-form. In their original report of the RHI, Botvinick and Cohen (1998) reported that the subjective strength of the illusion relied upon the synchrony of the tactile and visual stimuli: when the rubber hand and real hand were brushed asynchronously, subjects were less likely to report the illusion. Shimada, Fukuda, and Hiraki (2009) found that introducing delays between the visual and tactile stimuli reduced both subjective reports of the illusion and proprioceptive drift. These studies, among others, show that intermodal temporal synchrony is indeed an important cue for representing the body (Armel & Ramachandran, 2003; Ehrsson, Spence, & Passingham, 2004; Tsakiris & Haggard, 2005)

Visual information about what the body is typically like is also an important bodily-self cue (Costantini & Haggard, 2007; Haans, Ijsselstein, & de Kort, 2008; Tsakiris et al., 2010). For example, we most often view our hands from particular perspectives. Visual information from these perspectives (i.e., fingers pointing distally) are more *anatomically plausible*. Kalckert and Ehrsson (2012) compared the prevalence of the rubber hand illusion for different orientations of a rubber hand. When viewing a rubber hand in an *incongruent* orientation (i.e., rotated 180° relative to the participant's real hand) participants were significantly less likely to experience the illusion of ownership, than when viewing a rubber hand positioned in a *congruent* orientation. In a similar study, Ide (2013) found that participants perceived a stronger sense of ownership and showed greater proprioceptive drift for hands in more anatomically plausible orientations, than for anatomically implausible orientations. The proximity of a viewed hand also affects anatomical plausibility: the strength of the RHI decays when participants view a fake hand at distances greater than 30 cm (Lloyd, 2007). Using the RHI, we can introduce conflicts between visual and proprioceptive postural cues. Although the RHI shows that a slight mismatch (e.g., in lateral position) between seen (visual) and felt (proprioceptive) positions can be overcome when representing the body, these studies suggest that more extreme—and visually implausible—mismatches create an un-

likely combination of sensory inputs, preventing the brain from concluding that some seen body-part belongs to the agent.

In addition to the plausibility of viewed hand orientation, the plausibility of visual body-form also constrains the RHI. For example, Tsakiris et al. (2010) compared receptivity for the RHI when participants viewed either a realistic rubber hand or a plain wooden block. They found that participants failed to feel ownership of the sensations when viewing the wooden block. They also found that viewing the wooden block reduced proprioceptive drift, compared to the rubber hand stimulus. This suggests that multisensory integration of visual and tactile sensations is not a sufficient condition for body ownership, but rather that visual information about the body-form needs to approximately correspond to information about what the bodily-self is typically like.

These various experimental manipulations of the RHI show that the brain can make inferences about what constitutes a bodily stimulus using information from proprioceptive, visual, and tactile inputs. Evidence from the RHI provides clear evidence for two things about body representations. First, that the brain constructs representations of the body through evidence gathered from multiple sensory cues (Botvinick & Cohen, 1998). Second, that representations of the body are not fixed, but rather can be readily updated to accommodate new information (Graziano & Botvinick, 2002; Tsakiris, 2010).

As described above, RHI studies clearly demonstrate that body representations rely on multisensory processes. Evidence from the broader literature suggests the existence of dedicated neural mechanisms involved in processing multisensory bodily-self cues. Examples of this evidence can be found in neurophysiological studies of monkey brains. Single neuron responses in parietal and premotor cortex of macaque monkeys provide evidence for the integration of visual, tactile, and proprioceptive information at the single-neuron level (Fogassi et al., 1996; Graziano & Botvinick, 2002; Graziano, Hu, & Gross, 1997; Graziano, 1999). For example, Graziano, Yap, and Gross (1994) found many neurons in macaque ventral premotor cortex that respond to both tactile and visual stimuli near the contralateral hand. For these bimodal visual-tactile neurons, the visual receptive fields move with changes in the monkey's posture, but not with the position of the eyes. In this way, the visual receptive fields are *anchored* to the corresponding hand or arm of the tactile receptive field; they are not retinocentric. Evidence from

these neurophysiological studies shows that visual, tactile, and proprioceptive information about the body interact in neural processing.

Findings from monkey neurophysiology are often discussed in conjunction with evidence from human subjects. While many have used the bimodal cells in macaques as a homologue to explain how humans might form integrated multi-sensory representations of the body (di Pellegrino, Làdavas, & Farné, 1997; Farné, Pavani, Meneghello, & Làdavas, 2000; Làdavas, 2002), the existence of such bimodal neurons has not been directly observed in human brains (Holmes, Calvert, & Spence, 2004; Maravita & Iriki, 2004; Maravita et al., 2003). Still, evidence from functional magnetic resonance imaging (fMRI) studies of healthy, awake humans can help bridge the gap between these single neuron studies, and phenomena found in behavioural experiments. For example, Ehrsson et al. (2004) found that feelings of ownership of a rubber hand were correlated with neural activity in the premotor cortex. Makin, Holmes, and Zohary (2007) found interesting modulations of activity in anterior intraparietal sulcus, and concluded that this area is sensitive to proprioceptive and visual information about the body. These findings suggest the existence of neural circuits dedicated to the processing of visual and tactile information, and further that this processing is influenced by proprioceptive and visual hand information.

Behavioural studies of crossmodal *extinction* phenomena also suggest that representations of the body bind together information from touch, vision, and proprioception (Làdavas, di Pellegrino, Farné, & Zeloni, 1998), and further, that specific mechanisms for combining visual and tactile information exist in the human brain. In cases of *extinction*, patients with unilateral brain damage fail to perceive contralesional stimuli when simultaneously presented with ipsilesional stimuli. Some suggest this result could be explained by competing activation of neural representations (di Pellegrino et al., 1997; Farné, Dematte, & Làdavas, 2005; Maravita, Husain, Clarke, & Driver, 2001), and results in the patient only being able to perceive the dominant stimulus. For example, a patient with left tactile extinction might not be able to notice the presence of a touch to the left hand while the right hand is touched. Importantly, extinction patient studies have revealed that *crossmodal* extinction also occurs: both di Pellegrino et al. (1997) and Farné et al. (2005) report that the presentation of a *visual* stimulus can induce the extinction of a contralesional *tactile* stimulus. In these cases, the visual stimulus

prevents perception of a tactile stimulus, but only when the visual stimulus is presented in the immediate vicinity of the ipsilesional hand. It is conceivable that bimodal neurons, homologous to those found in macaque brains, underlie cross-modal extinction phenomena: activation of particular tactile neurons would also excite the neural representation of visual space on or near the hand (Maravita et al., 2003).

The literature discussed in this section clearly shows that representing the body involves the combination of multisensory bodily-self cues, and stored information about what the body is usually like. Behavioural paradigms, such as the RHI, reveal the importance of particular bodily-self cues for recognising the body. Further, findings from neurophysiological studies suggest dedicated neural mechanisms, thought to involve parietal and premotor areas, support the combination of multisensory bodily-self information. However, *how information from bodily-self cues might be combined* remains an open question. It is important to understand the cognitive processes that integrate information across modalities in own-body contexts. A variety of different approaches might be able to explain how the brain achieves this integration. In the following section, I introduce and describe some of these conceptual approaches, and empirical findings that motivate these views.

1.2 Combining bodily-self cues

As reviewed in the previous section, research clearly shows that various types of sensory information are informative of the bodily-self. However, it is not clear how the brain combines relevant bodily-self information. In this section, I describe different explanatory approaches to how information about the body might be combined.

1.2.1 Bodily-self cues: bottom-up and top-down

Proprioception, touch, and vision can provide redundant bodily-self cues. One view suggests that this sort of redundancy is an essential component in forming representations of the body: “bottom-up” accounts of body representations argue that appropriate intermodal correlations are what give rise to coherent representations of the body, and the feeling of *embodiment* experienced when viewing one’s own body (Armstrong & Ramachandran, 2003; Botvinick & Cohen, 1998).

Proponents of bottom-up accounts have appealed to findings from RHI studies. For example, Botvinick and Cohen (1998) found that introducing asynchrony between the visual stimulation of the rubber hand and the tactile stimulation of the real hand significantly reduced illusory experiences and proprioceptive drift. They conclude that this sort of ‘intermodal matching’ is sufficient for the incorporation of an object into the body representation, resolving any proprioceptive-visual incongruity. Armel and Ramachandran (2003) measured the incorporation of objects into the body representation using skin conductance response (SCR), as stronger SCRs are associated with fear response. SCRs were selected as an objective measure of embodiment, as harmful actions should elicit a more fearful response for objects that are embodied compared to those that are not. They found that subjects had higher SCRs for synchronous tactile and visual stimulation than for asynchronous stimulation when viewing a rubber hand. Interestingly, they found a similar pattern when subjects viewed the table surface being stroked. However, their experimental design might have invited transfer effects (Ma & Hommel, 2015). Despite this, Armel and Ramachandran (2003) concluded that the correlation of visual and tactile stimulation was enough to incorporate the table surface into the body representation. This evidence could support a bottom-up account of body representations: statistical correlations might be necessary and sufficient for representing some object as the body. However, purely bottom-up accounts of body representation might not be able to explain all of the findings. If representations of the body require information absent from primary sensory input, a bottom-up account is incomplete. As shown above, information about what the body is typically like (e.g., in terms of posture and form) influences the RHI. These findings suggest some top-down information plays a role in representing the body. This conflicts with the findings of Armel and Ramachandran (2003), raising doubts for their ‘table-as-body’ findings.

In contrast, top-down accounts are motivated by findings that suggest not all perceptual correlation can invoke ownership of some body part. Tsakiris and Haggard (2005) claim that bottom-up perceptual correlations are insufficient for representation of the body as their findings suggest both postural and anatomical plausibility are necessary for the elicitation of the RHI. Constraints on the acceptance of particular multisensory information indicates that there is some internal information to which sensory input is compared. Proponents of the top-down

view take this evidence to indicate that the brain maintains an internal representation of the body’s typical form and position. In this model, comparisons against this internal representation gate the processing of incoming multisensory information (Tsakiris, 2010). This could explain why an anatomically implausible object—like a block of wood, or an implausibly oriented hand—does not invoke the rubber hand illusion despite the temporal synchrony of visual-tactile stimulation (Tsakiris et al., 2010). Top-down accounts address the combination of body information by establishing the influence of internal information about how the body typically appears.

1.2.2 Optimal combination of bodily-self cues

Recently, theorists have appealed to principles from Bayesian-style interpretations of information processing in order to describe more nuanced accounts of body representations that take bodily-self signals and stored information into account (Apps & Tsakiris, 2014; Kilteni et al., 2015; Seth, 2013). Evidence shows that there are some anatomical and postural constraints on what we might accept as being the body (Tsakiris et al., 2010). Despite this, it is not clear how similar an artificial body part must be before it can be incorporated into one’s body representation. For example, skin colour and texture do not seem to affect ownership illusions (Schütz-Bosbach, Tausche, & Weiss, 2009)—further challenging the view that top-down information about bodily form gates particular multisensory information. Adopting a Bayesian framework may allow explanations of body representations to avoid a dichotomy between bottom-up and top-down modes of information combination, by describing how both sensory inputs and stored information could be optimally combined for body representation in perception and action (de Vignemont, 2010). While elements of Bayesian perceptual processing approaches do play a role in bottom-up accounts (Armel & Ramachandran, 2003), emerging *predictive coding* accounts of brain function are beginning to explore the implications of such a model in much greater detail.

Predictive coding accounts put forward that the brain generates perceptual content through generative, probabilistic inferences about the distal causes of sensory information (Seth, 2013). Within this framework, bottom-up sensory information and top-down cognitive information play different roles: top-down information is used to generate predictions of sensory events, and is compared to

the incoming sensory information, generating prediction errors (Apps & Tsakiris, 2014). The brain will minimise prediction errors by updating predictions of sensory events (Apps & Tsakiris, 2014). In the context of body representation, predictive coding accounts offer interesting solutions to the problem of informational combination. Different bodily-self cues, such as temporal synchrony, visual form, visual orientation, etc., might be combined in a statistically optimal fashion. In these accounts, the predictive weights for each type of sensory input are not fixed. This allows for the brain to optimally combine sensory inputs that differ in their reliability, depending on either modality or context (de Vignemont, 2010). Apps and Tsakiris (2014) appeal to this contextual-weighting of particular multisensory inputs to explain the RHI in a predictive coding framework: in the context of viewing an anatomically plausible hand, the synchrony of visual and tactile sensations is reliable information that a viewed hand is one's own.

In this section I have described different approaches that could explain the cognitive processes that underlie multisensory processing in own-body contexts. The current literature is lacking a clear explanation of how bodily-self cues interact with multisensory processing. For example, there is confusion as to whether integration of bodily-self cues depends on multisensory processing, or if multisensory processing is altered by the same bodily-self cues: it is argued that the rubber hand illusion *depends* on the synchronous presentation of visual-tactile stimuli (Armel & Ramachandran, 2003; Botvinick & Cohen, 1998; Shimada et al., 2009), but also that viewing hand-stimuli can influence the perception of synchrony for visual-tactile stimuli (Ide & Hidaka, 2013). Hence, critical investigation of body representations also needs to investigate the cognitive processes that underlie body perception. Understanding these cognitive processes is not only important for our theories of body representation, but also for our understanding of multisensory processing in general. This is especially important given the role of disrupted multisensory processing in clinical disorders, such as schizophrenia (Tschacher & Bergomi, 2011; Wallace & Stevenson, 2014) and autism (Foss-Feig et al., 2010; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011; Stevenson et al., 2014).

1.3 Seeing and feeling the bodily-self: visual, tactile, and proprioceptive interactions in own-body contexts

The literature reviewed in this chapter so far shows that there is considerable behavioural and neurophysiological evidence that multisensory bodily-self cues are combined to represent one's own body. However, the current literature has not clearly shown how bodily-self information is combined, or *how* body-context interacts with multisensory perception. Although this previous research has revealed clear interactions between bodily-self signals, the underlying cognitive mechanisms are not as clear. We can, however, investigate interaction between bodily-self cues and multisensory perception using behavioural paradigms and psychophysical techniques. In the following section, I review some important findings on how multisensory processes interact with different bodily-self cues. I suggest that this research has important implications for the study of multisensory information processing, but that the current literature offers no unambiguous answers to important questions relating to bodily-self cues and multisensory processing, and that there are several open questions.

In ordinary own-body contexts—that is, situations in which an individual perceives their own body—visual, tactile, and proprioceptive information is temporally bound, and highly correlated. This informational correlation allows for sensory expectations: if you move your own hand, you will likely see it moving synchronously. Do such sensory expectations alter how we perceive temporal relationships between stimuli in different modalities? Findings suggest they do: Hoover and Harris (2012) presented videos of participants' finger movements and manipulated the relative timing of the video feedback. They asked the participants to detect delays between performed and seen movements. They manipulated the orientation of the video to manipulate the plausibility of the bodily-self perspective. They found that sensitivity to small temporal delays between finger movements and visual feedback of the movement increased when viewing a hand from a plausible bodily-self perspective, compared to viewing a hand from an implausible perspective. In their subsequent study, Hoover and Harris (2015) replicated these findings for self-generated movement in other natural perspec-

tives, such as those seen when using a mirror. Again, they found that individuals could detect temporal asynchrony between seen and felt movements more precisely when viewing bodily movements from expected bodily-self perspectives, that is, from more plausible bodily-self orientations. Their findings show that plausible own-body contexts influence synchrony perception. This effect could be explained by a predictive mechanism, where sensory predictions influence the processing of multisensory information in particular contexts.

Supporting these findings, Zopf, Friedman, and Williams (2015) investigated the effect of visual form and hand-orientation on visual-proprioceptive synchrony perception. Using a virtual hand setup, they modulated the form and orientation of the visual stimuli to change the plausibility of seen bodily-self cues. In one experiment, participants either viewed a hand in an anatomically plausible orientation (fingers pointing distally), or an anatomically implausible orientation (fingers pointing proximally). When participants viewed an inverted virtual hand (an implausible bodily-self stimulus), their accuracy in judging small visual-proprioceptive delays was reduced in comparison to the plausible condition, supporting and extending findings of Hoover and Harris (2015). Together these studies demonstrate that the anatomical plausibility of viewed hand orientation affects the perception of temporal asynchrony between executed and seen movements.

From these findings, it is clear that bodily-self cues alter multisensory processing. However, the exact mechanisms underlying these multisensory interactions are not clear. One approach would suggest that representations of the body underlie changes to multisensory processing (Makin et al., 2008; Pavani, Spence, & Driver, 2000; Tsakiris, 2010). This approach would require bodily-self cues to be incorporated into the representation of the body—an updated body representation—as a causal antecedent to altered perceptual processing. In a sense, information potentially pertaining to the bodily-self would be gated: unable to modulate perceptual processing if not incorporated into the body representation. Such a model requires a categorical representation of bodily-self information. However, body representation, as suggested earlier, could be continuous: bodily-self cues might alter representations (and perceptual processing) increasingly based on the plausibility of their evidence. Such an approach suggests that bodily-self cues can modulate perceptual processing *directly*, perhaps without nec-

essarily changing experiences of the bodily-self. Further, these modulated perceptual processes might precede experiences of ownership, that is, illusory embodiment experiences might rely on these perceptual changes. Zopf et al. (2015) suggest that their findings support the view that bodily-self cues *directly* modulate visual-proprioceptive synchrony perception. Previous research suggests that merely viewing body parts (plausible in orientation and form for the bodily-self) does not lead to changes in body representation (Holmes, Snijders, & Spence, 2006; Longo, Cardozo, & Haggard, 2008). In their study, Zopf et al. (2015) interleaved the orientation conditions, limiting the visual exposure to bodily-self cues. Hence, they argued that their paradigm did not lead to dramatic changes in body representation. Rather, they suggest that visual-proprioceptive information in own-body contexts leads to the expectation of multisensory synchrony: hence, small multisensory temporal delays in own-body contexts violate expectations and are therefore highly salient. However, the plausible bodily-self stimuli in their experimental paradigm were themselves multisensory, which, despite being interleaved with implausible stimuli, might have led to changes in body representation. If the explanation of Zopf et al. (2015) is correct, then exposure to merely visual bodily-self information (e.g., of hands in an anatomically plausible orientation) should affect temporal processing of multisensory stimuli. If this view is incorrect, and bodily-self cues need to be integrated into representations of the body to alter multisensory processes, then visual bodily-self cues might not alter multisensory temporal perception. Instead, visual bodily-self cues might need to be combined with other multisensory bodily-self cues before these affects can be found.

Given previous findings and explanations from visual-proprioceptive experiments, visual bodily-self cues should influence multisensory temporal processing for other highly associated synchronous stimulus pairings (Zopf et al., 2015). In own-body contexts, visual-tactile events are a common example of synchronous multisensory stimuli. Many findings show that, as suggested by a predictive account (Zopf et al., 2015), bodily-self cues interact with visual-tactile processing (Igarashi, Kitagawa, & Ichihara, 2004; Pavani et al., 2000; Wada & Ide, 2016; Zopf et al., 2010).

Pavani et al. (2000) found that the presence of plausible bodily-self cues modulated visual-tactile spatial processing. Their study used a crossmodal congruency

paradigm: participants received tactile stimulation on either a thumb or index finger on either hand. They positioned four visual distractor lights onto two rubber hands, corresponding to the four locations of tactile stimulation on the real hand. Distractor lights could flash either congruently (in the same location as the tactile stimulation, e.g., both at the thumb) or incongruently (in a different location, e.g., one at the thumb, one at the finger). Pavani et al. (2000) asked participants to discriminate whether a tactile stimulus occurred in the ‘upper’ (finger) or ‘lower’ (thumb) position, and found that incongruent light flashes delayed tactile judgments compared to congruent light flashes. This performance difference is the crossmodal congruency effect. Importantly, Pavani et al. (2000) found that the rubber hand orientation modulated this effect. When positioned in an orientation congruent with the subject’s real arm posture, the effect was present. Importantly, they failed to find a significant effect when the rubber hands were in a visually implausible orientation for one’s own body. In a similar study, Igarashi et al. (2004) also found interactions between bodily-self cues and visual-tactile processing: the orientation of line drawings of hands (either congruent or incongruent with the participant’s hand) modulated visual-tactile interactions. These studies show that visual information about the bodily-self modulates visual-tactile interaction.

Body-context affects visual-proprioceptive temporal perception (Hoover & Harris, 2012, 2015; Zopf et al., 2015). This evidence suggests that body-context might also affect visual-tactile temporal perception (Zopf et al., 2015). The evidence above suggests that body-context affects visual-tactile spatial processing (Pavani et al., 2000; Zopf et al., 2010). However, these studies do not directly measure visual-tactile *temporal perception*, hence it is not clear if similar processes underlie both visual-tactile spatial and visual-proprioceptive temporal phenomena. Thus it is necessary to investigate if temporal perception is also changed for visual-tactile stimuli.

One promising study suggests that body-information-induced temporal changes do underlie visual-tactile interactions in own-body contexts: using a temporal order judgment (TOJ) task, Ide and Hidaka (2013) directly measured the effect of hand orientation on visual-tactile temporal processing. They found that the just-noticeable (temporal) difference between visual and tactile stimuli was larger when participants viewed the image of an upright hand than when viewing an upside-down hand image. Interpreting their findings, Ide and Hidaka (2013) claim that

visual hand images increase the *internal proximity* between visual and tactile stimuli: that is, that in own-body contexts, visual-tactile stimuli are more likely to be perceptually grouped than in other-body contexts, meaning that temporal asynchronies would be *more* difficult to perceive in own-body contexts.

Ide and Hidaka (2013) found an effect opposite to that of Hoover and Harris (2012, 2015); Zopf et al. (2015), namely that bodily-self cues made detection of multisensory asynchrony worse. However, Ide and Hidaka (2013) used a TOJ task, whereas Hoover and Harris (2012, 2015); Zopf et al. (2015) used SJ tasks. In the broader literature on multisensory temporal processing, researchers have highlighted issues in the interpretation of performance in temporal order judgment (TOJ) and synchrony judgment (SJ) tasks. For example, van Eijk, Kohlrausch, Juola, and van de Par (2008) show that TOJ tasks and (SJ) tasks (similar to those of Zopf et al. (2015) and Hoover and Harris (2015)) can lead to radically opposing estimates of subjective synchrony, even reversing the direction of audio-visual synchrony onsets. Given such disparate results, Love, Petrini, Cheng, and Pollick (2013) suggest that TOJ and SJ do not measure the same cognitive mechanism. Thus, despite the findings of Ide and Hidaka (2013), the evidence is inconclusive: it is not clear how bodily-self cues influence visual-tactile processing. It is not clear whether the findings of Zopf et al. (2015) and Hoover and Harris (2015) generalise to other multi-modal pairings, as one theory would predict (Zopf et al., 2015). Do bodily-self cues increase (as predicted by Ide and Hidaka (2013)) or decrease (as predicted by Zopf et al. (2015) and Hoover and Harris (2015)) the precision of visual-tactile temporal perception?

1.3.1 Interim summary: bodily-self cues and visual-tactile temporal processing

Identifying the bodily-self involves the interpretation of sensory evidence from a variety of sensory modalities, along with stored information about the usual constituents of the bodily-self. This means that the representation of the body is a multimodal construct, liable to changes in light of new evidence. It is clear that the mechanisms underlying bodily-self recognition process information from proprioceptive, visual, and tactile inputs. Empirical literature reveals that these informational inputs interact in own-body contexts. These studies offer insight

into the mechanisms that combine and represent such information, but gaps in the literature prevent clear answers to two particularly important questions. The experiments in this thesis are concerned with these two main questions. The first pertains to information processing in own-body contexts: do bodily-self cues directly modulate multisensory temporal processing? The second is concerned with disambiguating the evidence for changes in visual-tactile processing in own-body contexts: what are the bodily-self cues that affect visual-tactile temporal processing?

1.4 Research Questions

Bodily-self cues have been found to alter multisensory processing, but it is unclear if visual-tactile temporal processing is changed in own-body contexts. In this thesis, I examine the influence of bodily-self cues on visual-tactile asynchrony perception through two experiments. The experimental paradigms I use in the following chapters will help resolve conflicts between findings about the effects of bodily-self cues on visual-tactile temporal processing. These paradigms will also offer additional insight into questions about multisensory information processing in own-body contexts. There are two alternative models of multisensory information combination in own-body contexts. The first proposes that changes to multisensory processing rely on the incorporation of bodily-self cues into representations of the body, presumably at the later stages of perceptual processing (Makin et al., 2008; Tsakiris, 2010). The second suggests that bodily-self cues might directly affect perceptual processing without changes to bodily-self experience (Holmes et al., 2006; Zopf et al., 2015).

Hence, this thesis has two interrelated aims. First, I investigate whether the effect of bodily-self cues on visual-proprioceptive perception (Hoover & Harris, 2012, 2015; Zopf et al., 2015) generalises to visual-tactile temporal perception, as predicted by Zopf et al. (2015). Second, I examine whether such an effect could arise from plausible visual bodily-self information, or the combination of visual and multisensory bodily-self cues. The present study addresses these questions through two experiments, in which I present different bodily-self cues and use a two-interval forced-choice (2IFC) synchrony judgment (SJ) task to measure the threshold for visual-tactile asynchrony detection. SJ tasks provide an effec-

tive measure of perceived multisensory synchrony (van Eijk et al., 2008). I fit psychometric functions to individual participant's response data, as is standard psychophysical practice. I also perform goodness-of-fit analyses, which is an essential step in psychometric procedures (Wichmann & Hill, 2001). Psychophysical performance estimates are more accurate when functions are fit to individual participant's data (Spence, Baddeley, Zampini, James, & Shore, 2003).

In Experiment 1, I investigate the influence of visual hand information on visual-tactile asynchrony perception. In Experiment 2, I investigate the influence of visual hand information and additional multisensory bodily-self cues on visual-tactile asynchrony perception. To manipulate the plausibility of bodily-self cues, participants in both experiments viewed model hands in either an anatomically plausible or anatomically implausible orientation. In Experiment 2, I also introduce synchronous multisensory stimulation to induce illusory experiences of embodiment. I hypothesise that bodily-self cues would increase the sensitivity to visual-tactile asynchrony.

In this chapter, I reviewed the literature on the multisensory perception of the bodily-self and described open questions regarding visual-tactile temporal processing on own-body contexts. In the following chapters I present two experiments in which I examine the effects of plausible and implausible bodily-self cues on visual-tactile perception.

2 Visual bodily-self cues and visual-tactile asynchrony detection

In the first experiment, I investigated the influence of viewed hand orientation on visual-tactile asynchrony perception. Specifically, I investigated whether the precision of visual-tactile asynchrony detection was improved when viewing a hand in an anatomically plausible orientation compared to viewing a hand in an implausible orientation. I tested detection thresholds for both visual-leading and tactile-leading stimulus asynchronies.

Using the method of constant stimuli and a two-interval forced-choice (2IFC) task, I measured the proportion of correct asynchrony responses for the anatomically plausible and implausible hand orientation conditions for each participant. I fitted psychometric functions to the data from each condition and participant to estimate perceptual thresholds for asynchrony detection. I then performed paired comparisons for detection thresholds between conditions.

2.1 Method

2.1.1 Participants

Thirty-one undergraduate students took part in Experiment 1. Data from one participant were lost due to experimenter error, leaving thirty participants in the analysis for the experiment (mean age = 22 years, SD = 4.6 years, 21 female). All participants were right-handed and reported normal or corrected-to-normal vision. All participants gave written consent prior to the start of the experiment and received course credit for participation. The study was approved by the Mac-

quarie University Human Research Ethics committee.¹

2.1.2 Apparatus and materials

Stimulus presentation apparatus. A custom-made experimental apparatus housed the experimental stimuli (see Figure 2.1 for a depiction of the experimental setup). The apparatus housed two plaster hands in two separate compartments. This design allowed for the illumination of one compartment at a time. A tactile stimulator was located at the midline of the apparatus, embedded in the base of a third compartment on a parallel plane 80 mm below the plaster hand compartments. Two LEDs (one for each plaster hand) were located at the tips of the plaster hands, equidistant from the location of the tactile stimulator. Participants sat at a desk and placed their right hands in the third compartment, resting their middle finger pad on the tactile stimulator, approximately corresponding to the participant's midline. While in the apparatus, the participant's right hand was hidden from view.

Computers and hardware. A Dell Optiplex 9010 running Presentation software (version 18.1, Neurobehavioral Systems) controlled stimulus presentation and response collection. An LCD display (Samsung SyncMaster SA950) placed behind the stimulus presentation apparatus illuminated one of the plaster hands during experimental trials. Participants responded using a custom-built three-button response box (USB, U-HID nano) that encased two black buttons on the left and right and one red button on the top.

To present the visual and tactile stimuli, I used a Dancer Design² TactAmp 4.2. This could power and control the timing of both the LEDs (5 mm, red) and the tactile stimulator via a D25 serial port. The tactile stimulator was a Dancer Design tactor vibrotactile stimulator (electromagnetic solenoid-type, probe height: 12 mm, diameter: 18 mm). The movement of the tactor created a very soft sound. To completely mask any sound from the Tactor, an Apple iPod played continuous white noise through circumaural, closed-back headphones (Sennheiser HD 280 pro, 64 ohm) at a comfortable volume for each participant.

Embodiment questionnaire. I designed the experiment to investigate effects of visual hand-orientation without attempting to induce embodiment illusions. In particu-

¹See Appendix C for Ethics Approval.

²<http://www.dancerdesign.co.uk/>



Figure 2.1: Stimulus presentation apparatus. Participants completed half of the trials with the plausibly oriented hand on the left, and half the trials with the plausibly oriented hand on the right.

Table 2.1: Embodiment questionnaire items. The order of questionnaire items was randomised each time. Participants indicated their level of agreement with each item using a seven-point Likert scale, ranging from -3 (disagree) to $+3$ (agree). The items were adapted from those used by Longo, Schüür, et al. (2008).

1.	It seemed like I was looking directly at my own hand, rather than at a plaster hand.
2.	It seemed like the plaster hand began to resemble my real hand.
3.	It seemed like the plaster hand belonged to me.
4.	It seemed like the plaster hand was my hand.
5.	It seemed like the plaster hand was part of my body.
6.	It seemed like my hand was in the location where the plaster hand was.
7.	It seemed like the plaster hand was in the location where my hand was.
8.	It seemed like the touch I felt was happening at the location of the red light.
9.	It seemed like the touch I felt was caused by the red light.
10.	It seemed like I could have moved the plaster hand if I had wanted.
11.	It seemed like I was in control of the plaster hand.

lar, the plausible and implausible orientation conditions were interleaved. However, the task stimuli themselves were multisensory and thus opened the possibility of embodiment changes. Thus, I also asked participants about their embodiment experiences, employing an embodiment questionnaire. Participants indicated their level of agreement on a seven-point Likert scale, ranging from -3 ('disagree') to $+3$ ('agree'), with eleven statements pertaining to the feeling of embodiment. The statements were adapted from the ten embodiment component questionnaire items from Longo et al. (2008). The original questionnaire items refer to rubber hands, and visible paintbrush stimuli. This experiment involved different stimuli (plaster hands, LEDs, and a vibrotactile stimulator), so the questionnaire items were changed accordingly. To make sense given these stimuli, adapting one of the original questionnaire items required the use of two separate items. Hence, items 8 and 9 were adapted from one of the original questionnaire items ("it seemed like the touch I felt was caused by the paintbrush touching the rubber hand") to avoid confusion. See Table 2.1 for a list of these items.

2.1.3 Stimuli

Visual stimulus. The visual stimulus in the 2IFC task was a 15 ms LED flash.

Tactile stimulus. The tactile stimulus in the 2IFC task was a 15 ms pulse of the vibrotactile stimulator, which delivered a tap to the middle finger pad.

Plaster hands. In each trial, participants viewed one of two identical anatomically-realistic model hands that were presented in different orientations. Each model hand was an unpainted, off-white plaster casting from the same high-detail (25 micron-accurate alginate) mould of an adult male right hand. The plaster hand

was ~ 190 mm from middle fingertip to wrist, and ~ 120 mm across at the widest point (see Appendix A for a detailed photograph).

2.1.4 Design and Procedure

The experiment used a repeated-measures design, and systematically manipulated three independent variables: (1) hand orientation condition (plausible: fingers pointing away from the body, implausible: fingers pointing towards the body), (2) stimulus onset asynchrony (SOA = 40, 80, 120, 160, 200, 240, or 280 ms), and (3) the presentation order of asynchronous stimuli (visual-leading asynchrony, tactile-leading asynchrony).

Task and trials. An unspeeded 2IFC task was employed. Each trial comprised two intervals, both presenting a visual and a tactile stimulus. One interval contained a synchronous visual-tactile presentation, whereas the other contained an asynchronous visual-tactile presentation (SOA between 40 and 280 ms). Participants were asked to indicate in which interval (first or second) there was a delay between the visual and tactile stimuli.

For the duration of a trial, participants viewed the plaster hand in either the plausible or implausible orientation. Each trial began by illuminating the plaster hand. After 1000 ms the first interval was presented, and the second interval followed after an inter-stimulus interval of 1000 ms. The illumination ended 300 ms after the end of the second interval. Participants then indicated whether the first or second interval contained a delay between the visual and tactile stimuli. Participants pressed the left button to indicate the first interval, and the right button to indicate the second interval. The next trial began 500 ms after participants responded.

Both orientation conditions were interleaved, and presented pseudo-randomly (one orientation condition never appeared more than three times in succession). To achieve this, the presentation apparatus displayed one orientation condition (plausible or implausible) on the left, and one on the right. To avoid potential effects of displayed side on detection performance in either orientation condition, each participant completed half of the trials with the plausibly-oriented plaster hand on the left (implausibly-oriented hand on the right), and the other half of the trials with the plausibly oriented plaster hand on the right (implausibly-oriented hand on the left). The order of plausible-orientation and side (first half on left,

second on right) was counterbalanced across participants.

Before the experiment, participants practiced the 2IFC task for 20 trials, and were given feedback on their performance. The practice trials involved longer SOAs (300 ms) to minimise practice effects. Before the experiment, the participant removed any jewellery (e.g., rings, watches, bracelets) from their right hand.

The experimental trials comprised 28 different asynchronous presentation types, one for each combination of orientation condition (2 levels), SOA (7 levels), and asynchrony-order (2 levels). Each trial type was presented 30 times, amounting to 420 trials per orientation condition and 840 trials in total for each participant. The room was darkened during the experimental task.

Participants took seven self-paced breaks during the task, and could resume the task by pressing the red button. Participants received no feedback on their performance in experimental trials.

After the 2IFC task, participants filled out the embodiment questionnaire for each orientation condition separately (order of conditions counterbalanced across participants). The 11 rating statements were randomised each time.

The entire experimental session took approximately 1.5 hours to complete.

2.1.5 Data analysis

To assess the precision of visual-tactile asynchrony detection, I fitted individual psychometric functions to the proportion of trials in which the participant correctly identified the asynchronous stimulus interval. This yielded four fits per participant, one for each orientation condition and asynchrony order combination.

The Palamedes toolbox for MATLAB (Prinz & Kingdom, 2009) was employed to fit a Weibull function using a maximum-likelihood criterion, with a lower asymptote (guess rate) fixed to 50%. Asynchrony detection thresholds (80.3% correct performance level) were then taken from the fitted functions.

To measure how well the fitted psychometric functions (and their derived threshold values) accounted for the participant response data, I performed a goodness-of-fit analysis for each fitted function and obtained values for the “deviance” (Dev , transformed likelihood ratio). I obtained deviance p -values ($pDev$; range from 0 to 1, larger values indicate better fits) with a bootstrap analysis comprising 10,000 simulations per fitted function. A $pDev < .05$ indicates an unacceptably poor fit

(Kingdom & Prins, 2010).

Exclusion criteria. In Experiment 1 there were two possible asynchronous trial types: visual-leading asynchrony and tactile-leading asynchrony. The results for each asynchrony type have been analysed separately with individual exclusions. This is comparable to other analyses that report detection thresholds for inter-modal asynchrony in one stimulus presentation order (Hoover & Harris, 2012, 2015; Zopf et al., 2015).

The aim of this experiment was to compare detection thresholds between the two orientation conditions. A poor estimate of either threshold would yield a noisy measure of performance difference across the two orientation conditions. Hence, participant data with poor estimates of detection thresholds were excluded from the analyses. I employed a three-step process for exclusion.

Data analysis for each asynchrony type (visual-leading and tactile-leading) began with the same participants ($N = 30$) and proceeded as follows. First, if the software fitting the function failed to converge ('failed fits') on a solution for either orientation condition (plausible or implausible), both psychometric functions (one for each condition) were excluded from the analysis. Second, participant data were excluded if $pDev < .05$ for either one or both psychometric functions ('unacceptably poor fits').

Third, outliers for the mean threshold difference were excluded. An extreme difference in one individual's performance between plausible and implausible conditions is not necessarily indicative of a large effect, but can be the result of an inaccurate threshold estimate derived from an overfitted function and noisy response data. Given the findings from previous studies, I did not expect to find extreme differences in performance between the orientation conditions. Hence, if the difference in asynchrony detection threshold between the plausible and implausible conditions (the effect of interest) was greater than 2 SD from the mean group difference for any individual, data for that participant were also excluded.

Planned comparisons. The statistical analysis of asynchrony thresholds included paired t -tests for comparisons between orientation conditions, with alpha set at 5%. For all means comparisons, I report Cohen's d as an indicator of effect sizes. By convention, these minimum values of Cohen's d are used to represent effect sizes: 0.2 = small effect, 0.5 = medium effect, and 0.8 = large effect (Cohen, 1992).

I used the R statistical computing environment and language (Team, 2014) to run the statistical analyses. For data visualisation, I also used ggplot2 (Wickham, 2009) and reshape2 (Wickham, 2007) R packages.

2.2 Results

2.2.1 Exclusions

Visual-leading asynchrony data. For the visual-leading asynchrony trials there were no failed fits. Data from eleven participants were removed because either one or both fits were unacceptably poor. Data from a further two participants were removed because they were outliers. After exclusions, 17 participants (mean age = 21 years, SD = 3.7 years, 12 female) were included in the analysis of visual-leading asynchrony detection.

Tactile-leading asynchrony data. For the tactile-leading asynchrony trials, one participant's data were removed due to a failed fit. Data from a further eight participants were removed because either one or both fits were unacceptably poor. Data from a further two participants were removed because they were outliers. After exclusions, 19 participants (mean age = 21 years, SD = 3.0 years, 14 female) were included in the analysis of tactile-leading asynchrony detection.

2.2.2 Visual-leading asynchrony detection thresholds

A paired t-test revealed no significant difference in mean visual-leading asynchrony detection performance between plausible ($M \pm \text{SEM} = 152 \text{ ms} \pm 16 \text{ ms}$) and implausible ($M \pm \text{SEM} = 146 \text{ ms} \pm 12 \text{ ms}$) orientation conditions (mean difference = 6 ms, $t(16) = 0.80$, $p = .43$, Cohen's $d = 0.1$). Figure 2.2 depicts the group mean proportion of times participants correctly identified the interval which presented the visual-leading delay for the range of SOAs for each orientation condition. As can be seen in this figure, the mean proportions across the SOAs were quite similar between the two orientation conditions.

Comparison of Psychometric function data: slope and goodness-of-fit. A paired t-test also revealed no significant difference in mean slope between plausible ($M \pm \text{SEM} = 1.36 \pm 0.096$) and implausible ($M \pm \text{SEM} = 1.27 \pm 0.107$) orientation conditions (mean difference = 0.09, $t(16) = 0.68$, $p = .51$, Cohen's $d = 0.22$). Further, there

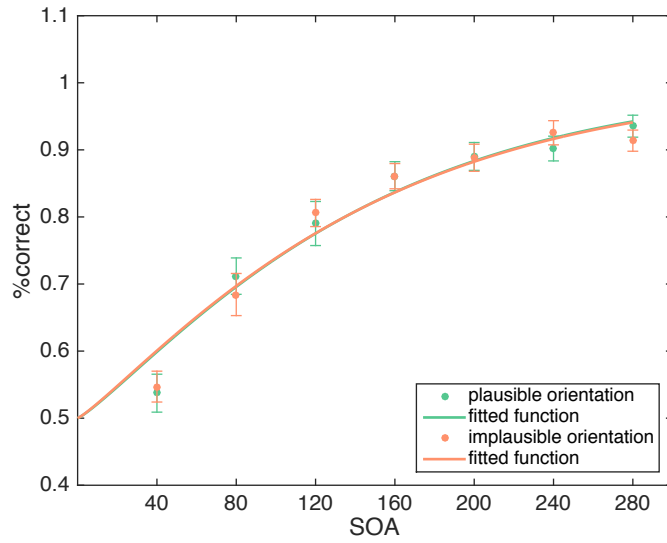


Figure 2.2: Mean proportion of correct responses for all SOAs for visual-leading asynchronies. A Weibull function is fitted to the mean group responses for demonstrative purposes only; estimations of asynchrony detection thresholds were calculated on an individual basis. Error bars represent the SEM.

was no significant difference in Dev between plausible ($M \pm SEM = 5.57 \pm 0.69$) and implausible ($M \pm SEM = 6.00 \pm 0.68$) orientation conditions (mean difference = 0.43, $t(16) = 0.42$, $p = .68$, Cohen's $d = 0.15$).

2.2.3 Bayesian analysis of asynchrony detection performance

The non-significant findings above could indicate either (1) that visual and tactile synchrony perception are unaffected by bodily-self cues (i.e., that there is no effect of viewed hand orientation on visual-tactile temporal processing), or (2) that these data are not sufficiently sensitive to reveal an effect (Dienes, 2014). Given the assumptions inherent to frequentist (traditional) statistical analyses, one cannot coherently argue for (1) over (2) from a p -value of greater than .05 (Cohen, 1990, 1994).

To test whether the null hypothesis (that detection thresholds are not reduced in the plausible condition compared to the implausible condition) or the alternative hypothesis (that detection thresholds are reduced in the plausible condition compared to the implausible condition) was more likely *given these data*, I performed a Bayesian analysis of the detection threshold data. Specifically, I calculated Bayes

factors, B , to assess the relative strength of the evidence in support of these two theories.

Bayes factor. B assesses the strength of evidence for one theory (the alternative hypothesis) against another (the null hypothesis). B ranges from zero to infinity. A B of 1 indicates maximal insensitivity of the experimental evidence. A B greater than 1 indicates that the data support the experimental hypothesis, whereas a B less than 1 indicates that the data support the null hypothesis (Dienes, 2011, 2014). B does not represent an acceptable alpha value, but rather offers *continuous* evidence for some hypothesis, so values closer to infinity or closer to zero offer stronger evidence for the alternative hypothesis or the null hypothesis, respectively; B allows one to assess how decisively the data support an hypothesis (Dienes, 2011, 2014; Jeffreys, 1939; Wagenmakers et al., 2015). Jeffreys (1939) suggests that $B > 3$ offers substantial evidence for the alternative hypothesis and $B < 1/3$ offer substantial evidence for the null hypothesis.

Setting priors. To calculate B , it is necessary to define prior distributions for the hypotheses (Dienes, 2011, 2014; Wagenmakers et al., 2015). I defined the prior distribution as follows. To represent the predictions of the theory (i.e., my experimental hypothesis), I used a half-normal distribution with a SD set to the experimentally predicted effect size. This practice is recommended by Dienes (2014) for theories with a likely predicted effect size, that is, effect estimates for which there are predictions in the literature. A half-normal distribution indicates that values closest to the null (i.e., small mean differences) are most probable. The effect size (expected mean difference between plausible and implausible conditions) was set at 20 ms, based on an average figure of two mean differences reported by Zopf et al. (2015) (18 ms) and Hoover and Harris (2015) (22 ms).

To show how cumulative evidence converges in support of one hypothesis, Figure 2.3 depicts the iterative calculations of B for each additional participant. At $N = 17$ participants, the calculation of $B = 0.20$, indicating that the data support the null hypothesis (Jeffreys, 1939). Hence, these data offer substantial evidence against the hypothesis that viewing a hand in an anatomically plausible orientation increases the precision of visual-tactile asynchrony detection compared to an anatomically implausible orientation.

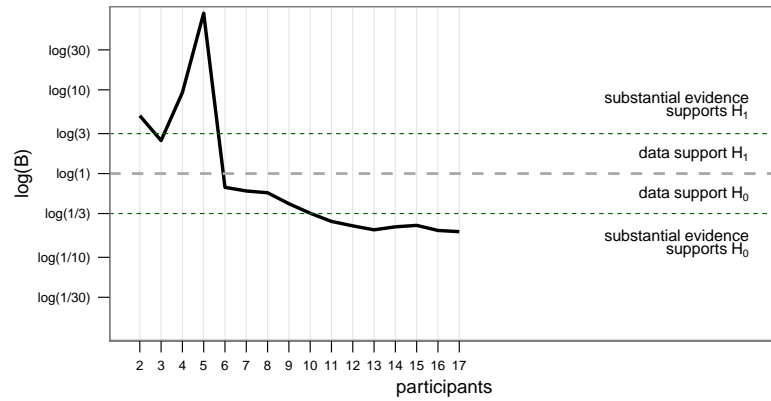


Figure 2.3: Iterative Bayes factor calculations for visual-leading asynchrony detection thresholds. As evidence accumulates (increased number of tested participants), the ratio of the likelihood increases in favour of the null hypothesis. Note that Bayes factor is plotted on a logarithmic scale. Also note the variability at small N .

2.2.4 Tactile-leading asynchrony detection thresholds

A paired t-test revealed no significant difference in mean tactile-leading asynchrony detection performance between plausible ($M \pm \text{SEM} = 221 \text{ ms} \pm 16 \text{ ms}$) and implausible ($M \pm \text{SEM} = 223 \text{ ms} \pm 17 \text{ ms}$) orientation conditions (mean difference = 2 ms, $t(18) = 0.29$, $p = .78$, Cohen's $d = 0.03$). Figure 2.4 depicts the group mean proportion of times participants correctly identified the interval which presented the tactile-leading delay for the range of SOAs for each orientation condition. As can be seen in this figure, the mean proportions across the SOAs were quite similar between the two orientation conditions.

Comparison of Psychometric function data: slope and goodness-of-fit. A paired t-test revealed no significant difference in mean slope between plausible ($M \pm \text{SEM} = 2.4 \pm 0.31$) and implausible ($M \pm \text{SEM} = 2.4 \pm 0.28$) orientation conditions (mean difference = 0.05, $t(18) = 0.12$, $p = .91$, Cohen's $d = 0.04$). Further, there was no significant difference between the goodness-of-fit between plausible ($M \pm \text{SEM} = 5.25 \pm 0.66$) and implausible ($M \pm \text{SEM} = 6.38 \pm 0.50$) orientation conditions (mean difference = 1.13, $t(18) = 1.24$, $p = .23$, Cohen's $d = 0.44$).

Bayes factor. Using the same priors as for the earlier analysis of visual-leading asynchrony detection, I calculated B for tactile-leading asynchrony detection. Figure 2.5 shows the iterative calculations of B for tactile-leading asynchronies. At $N = 19$, $B = 0.45$, indicating that these data offer more support for the null hypothesis.

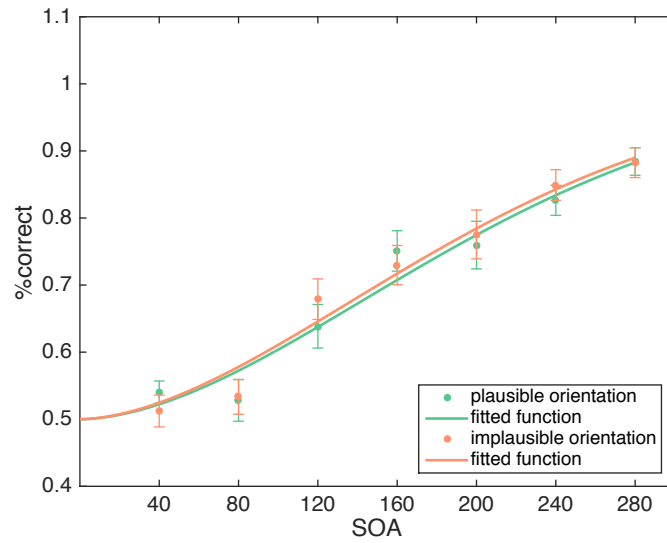


Figure 2.4: Mean proportion of correct responses for all SOAs for tactile-leading asynchrony. A Weibull function is fitted to the mean group responses for demonstrative purposes only; estimations of asynchrony detection thresholds were calculated on an individual basis. Error bars represent the SEM.

sis than for the alternative hypothesis. While thresholds for *substantial* evidence are conventionally regarded as $B > 3$ or $B < 1/3$, these are only suggested values: calculations of B are unlike significance levels, in that they offer continuous evidence (Wagenmakers et al., 2015). Importantly, the degree of belief in one hypothesis over another should be adjusted by (sensible) evidence: Jeffreys (1939) argues that the more supported hypothesis (regardless of strength) is to be used until evidence suggests otherwise. Hence, here, we again see more evidence for null hypothesis than for an effect of bodily-self cues on asynchrony detection precision.

2.2.5 Embodiment questionnaire

I tested the rating scale means for normal distributions because the questionnaire data could potentially be skewed. I found no evidence for non-normal distributions in any of the mean questionnaire ratings (Shapiro-Wilk test, all $p > .05$). Thus, the normality assumption was not challenged and I conducted parametric paired comparisons of questionnaire data.

Comparisons of mean embodiment questionnaire ratings across orientation conditions surprisingly revealed significant differences in both data sets.

Visual-leading asynchrony data. A paired t-test indicated that mean levels of agree-

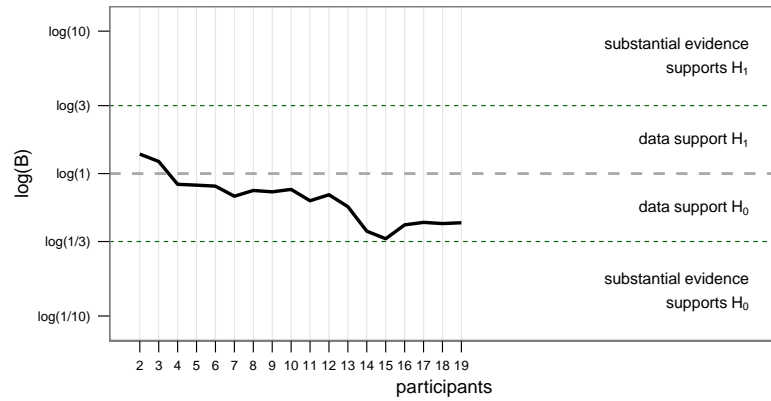


Figure 2.5: Iterative Bayes factor calculations for tactile-leading asynchrony detection thresholds. As evidence accumulates, the ratio of the likelihood increases in favour of the null hypothesis.

ment with the questionnaire items were significantly higher in the plausible condition ($M = 4.8$, $SD = 1.0$) than the implausible condition ($M = 2.7$, $SD = 1.0$), $t(16) = 5.95$, $p < .001$, Cohen's $d = 1.39$.

Tactile-leading asynchrony data. A paired t-test indicated that mean levels of agreement with the questionnaire items were significantly higher in the plausible condition ($M = 4.9$, $SD = 0.9$) than the implausible condition ($M = 2.7$, $SD = 1.3$), $t(18) = 7.19$, $p < .001$, Cohen's $d = 1.43$.

Correlations. To test if there was an association between changes to body perception and visual-tactile asynchrony perception, I examined the correlation between embodiment measures and detection thresholds. There were no significant correlations between the magnitude of embodiment questionnaire score (plausible score – implausible score) and the difference in asynchrony detection threshold between plausible and implausible conditions in either the visual-leading (Pearson's $r(15) = -.34$, $p = .18$) or tactile-leading (Pearson's $r(17) = .03$, $p = .92$) asynchrony conditions.

2.3 Discussion

In this experiment, I investigated the influence of visual bodily-self information on the precision of visual-tactile asynchrony detection, in both asynchrony directions. I manipulated the plausibility of visual information for hand ownership and measured the proportion of correct asynchrony judgments for a variety of SOAs,

deriving thresholds for asynchrony detection as a measure of performance. The dependent variable was the difference in asynchrony detection performance between plausible and implausible hand orientation conditions in either asynchrony type (visual-leading, tactile-leading).

Frequentist analyses of the data revealed no significant difference in performance (i.e., a difference in asynchrony detection threshold) between the plausible orientation condition and the implausible orientation condition for either visual-leading or tactile-leading asynchronies. There were also no significant differences in slope between the orientation conditions, suggesting that there was no difference in contrast precision for either orientation condition. Furthermore, there were no significant differences in goodness-of-fit for the psychometric functions between the orientation conditions, suggesting that neither orientation condition yielded more accurate performance measures.

A Bayesian analysis revealed that the detection threshold data were not too insensitive to reveal an effect, but rather that the experimental findings strongly support the null hypothesis. From here I conclude that the manipulation of visual information about the bodily-self does not increase precision of visual-tactile asynchrony detection.

Given previous findings (Hoover & Harris, 2012, 2015; Zopf et al., 2015), this result was unexpected. However, important aspects of this study differed from previous paradigms. The paradigm in Experiment 1 involved only visual manipulations of stimuli. The paradigms utilised by Zopf et al. (2015) and Hoover and Harris (2012, 2015) involved detecting asynchronies between active movement and seen movement. Efferent and afferent information in such self-generated stimuli potentially increase the plausibility for ownership of the visual information in these tasks. Participants in these paradigms have access to multisensory body cues (visual, tactile, and proprioceptive), which might be necessary for an increase in the expectation of multisensory synchrony, and an effect of body-context on multisensory temporal perception.

Another difference between the current study and previous research is the mode of condition presentation. In other studies that found interactions between visual hand orientation and visual-tactile processing, the orientation conditions were presented in blocks (Ide & Hidaka, 2013; Pavani et al., 2000), which tends to enhance the possibility of RHI.

Despite the differences between the paradigm in Experiment 1 and the RHI paradigms mentioned above, I found significant differences in embodiment report score averages between plausible and implausible conditions (for both visual-leading and tactile-leading data sets). These differences are typically only found when there is multisensory stimulation and when hand orientation conditions are presented for periods longer than a few seconds (Ehrsson et al., 2004). However, it may be possible that the task-stimuli in Experiment 1 did lead to changes to embodiment, which were accumulated for the different orientation conditions over time. Alternatively, participants might not have experienced changes in embodiment, and other factors may have influenced their response patterns. To conclusively test if multisensory bodily-self cues—instead of only visual bodily-self cues—can lead to changes in visual-tactile synchrony perception, I conducted Experiment 2. Further, I included a more objective behavioural measure of embodiment in Experiment 2. I will discuss the reliability of the questionnaire data further in Chapter 4.

I also looked at the correlation between the embodiment questionnaire score and the difference in asynchrony detection performance to test if participants who reported higher questionnaire scores differed more in their performance between conditions. This correlation was not significant.

Given the differences between my paradigm and those used in previous research, it is conceivable that the bodily-self cues presented in Experiment 1 were not strong enough to affect visual-tactile temporal processing. Hence, in the following study (Experiment 2) I modified my experimental paradigm to further increase the plausibility of bodily-self cues. To do this, I blocked the presentation of orientation conditions, and presented multisensory (visual-tactile) bodily-self cues to participants in addition to presenting plaster hands in different orientations. Further, given that many of the data in Experiment 1 were excluded on account of badly-fitted psychometric functions, I simplified the task in Experiment 2 in order to reduce noisy response data, and only presented tactile-leading SOAs. This is in line with the paradigms used by Zopf et al. (2015) and Hoover and Harris (2012, 2015), which could only introduce delays of the visual stimuli.

3 Multisensory bodily-self cues and visual-tactile asynchrony detection

In the second experiment, I investigated the influence of viewed hand orientation combined with synchronous touch on visual-tactile asynchrony perception, for tactile-leading stimulus asynchronies only. As in Experiment 1, I employed a two-interval forced choice task, and measured the proportion of correct asynchrony responses for the plausible and implausible conditions. I fitted psychometric functions to these data to calculate perceptual thresholds for asynchrony detection.

The methods for Experiment 2 were the same as Experiment 1, besides the differences described in the following section.

3.1 Method

3.1.1 Participants

Thirty-one undergraduate students took part in Experiment 2 (mean age = 23 years, $SD = 7.7$ years, 18 female). All participants were right-handed and reported normal or corrected-to-normal vision. All participants gave written consent prior to the start of the experiment and received course credit for participation. The study was approved by the Macquarie University Human Research Ethics committee.¹

¹See Appendix C for Ethics Approval.

3.1.2 Apparatus and materials

Stimulus presentation apparatus. To accommodate the addition of multisensory bodily-self cues in Experiment 2, a different experimental setup was used. A custom-made experimental apparatus housed the experimental stimuli (see figure 3.1 for a depiction of the experimental setup). The plaster hand sat on a flat surface on top of the apparatus, in one of two possible orientation conditions. A red LED was located in the geometric centre of the top surface. The plausible and implausible orientations were rotated 180° around the LED. While in either orientation condition, the middle fingertip of the plaster hand made contact with the LED. The tactile stimulator was located below the LED, embedded in a flat plane 125 mm below the top of the apparatus. Both planes were parallel and level.

Each participant sat at a desk and placed their right hand inside the apparatus, resting their middle finger pad on the tactile stimulator. While in the apparatus, the participant's right arm was hidden from view.

Computers and hardware. This experiment used the same hardware and software for data collection as Experiment 1. However the LCD display was not used: given that the orientation conditions were blocked, Experiment 2 did not require dynamic illumination.

Haptic Proprioception Gauge. A custom-made gauge allowed for the measurement of proprioceptive information, independent of visual input. The instrument (detailed in figure 3.2) consisted of a fixed, vertical L-beam (aluminium extrusion, 650 mm) and a manual clamp. The L-beam allowed for guided movement of the clamp along a vertical axis. On the side opposite the participant, and visible to the experimenter, the beam was marked with a scale in millimetres. The scale indicated the vertical position of the clamp on the beam. There were no measurement markings on the participant side. Due to mechanical play, measurement precision was limited to ± 1 mm.

Embodiment questionnaire. As an additional measurement of the embodiment experience, I employed an embodiment questionnaire similar to that of Experiment 1, also adapted from the ten embodiment component questionnaire items from Longo, Schüür, et al. (2008). However, given the stimuli in Experiment 2, the additional item used in Experiment 1 was not required here. Participants indicated their level of agreement (on a seven-point Likert scale) with ten statements

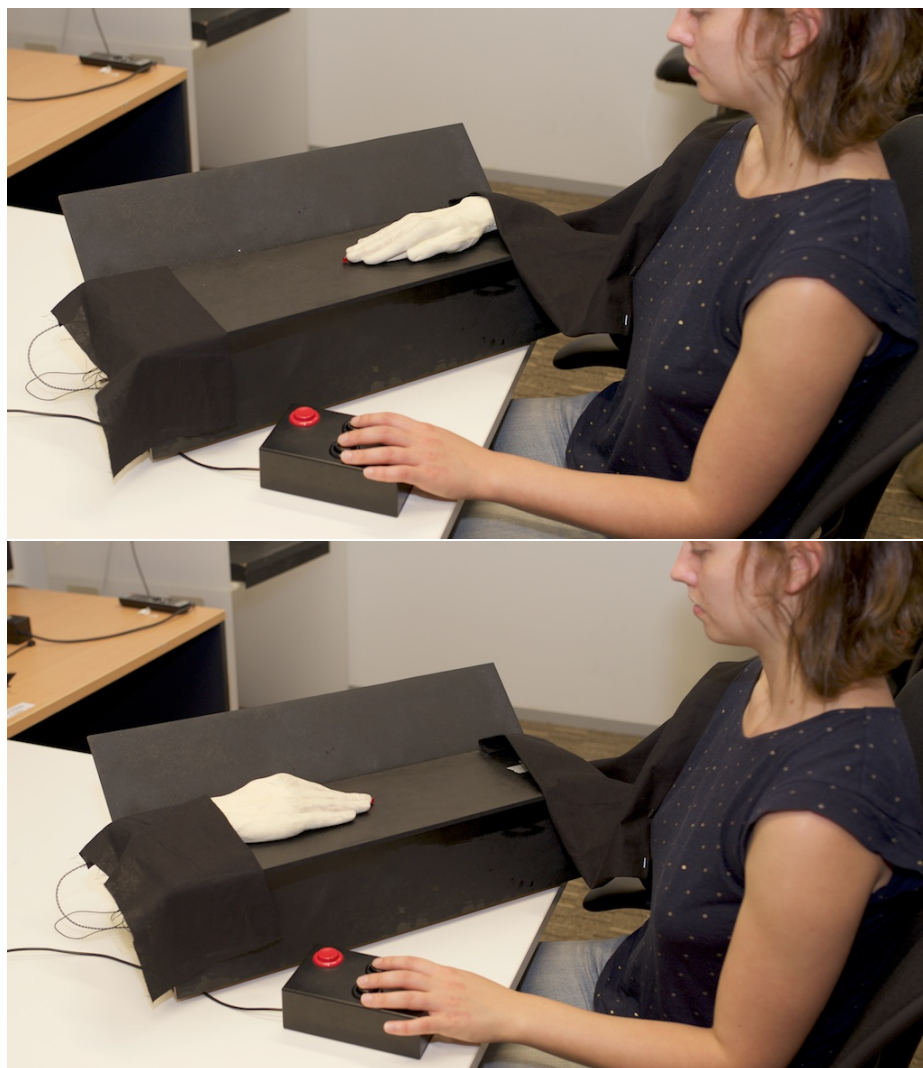


Figure 3.1: Stimulus presentation apparatus



Figure 3.2: (Blind-) Haptic Proprioception Gauge. Each participant indicated the perceived height of their right hand while their eyes were closed. Measurements were taken before and after each orientation condition.

Table 3.1: Embodiment questionnaire items. The order of questionnaire items was randomised each time. Participants indicated their level of agreement with each item using a seven-point Likert scale, ranging from – 3 (disagree) to + 3 (agree). The items were adapted from those used by Longo, Schüür, et al. (2008).

1.	It seemed like I was looking directly at my own hand, rather than at a plaster hand.
2.	It seemed like the plaster hand began to resemble my real hand.
3.	It seemed like the plaster hand belonged to me.
4.	It seemed like the plaster hand was my hand.
5.	It seemed like the plaster hand was part of my body.
6.	It seemed like my hand was in the location where the plaster hand was.
7.	It seemed like the plaster hand was in the location where my hand was.
8.	It seemed like the touch I felt was caused by the paintbrush touching the plaster hand.
9.	It seemed like I could have moved the plaster hand if I had wanted.
10.	It seemed like I was in control of the plaster hand.

pertaining to the the feeling of embodiment. See table 3.1 for a list of these items.

3.1.3 Stimuli

Visual and tactile stimuli. This experiment used the same visual and tactile stimuli at the same levels of intensity as Experiment 1.

Plaster hand. During each block, participants viewed an anatomically-realistic model hand in one of two orientations. The plaster hand for this experiment was different from those used in Experiment 1: participants viewed the plaster hand from a more natural vantage point, hence a new casting with more visible details (i.e., greater than 180 degrees of relief) was used. The modal hand was an unpainted, pale-yellow plaster casting from a high-detail (25 micron-accurate alginate) mould of an adult male right hand (the same subject from Experiment 1). The plaster hand was ~190 mm from middle fingertip to wrist, and ~110 mm across at the widest point (see Appendix B for detailed photographs).

3.1.4 Design and Procedure

The experiment used a repeated-measures design, and systematically manipulated two independent variables: (1) hand orientation condition (plausible, implausible) and (2) stimulus onset asynchrony (SOA = 40, 80, 120, 160, 200, 240, or 280 ms).

Multisensory embodiment stimulation. To manipulate the illusory embodiment of the plaster hand, participants received synchronous multisensory stimulation in both orientation conditions. Using a flat 50mm paintbrush, the experimenter stroked both the plaster hand and the participant’s right hand simultaneously.

The brush was wide enough to cover two fingers at the same time. Participants were instructed to focus on the plaster hand during stimulation.

The experimenter maintained an alternating stroking pattern consisting of 5 strokes to the index and middle fingers, and 5 strokes to the ring and little fingers. Each stroke began at the first knuckle (metacarpophalangeal joint) and progressed to the fingertips, taking ~ 600 ms. The hands were stroked at a rate of 1200 ms (0.83 Hz). The experimenter listened to a metronome to maintain accurate timing. The stroking pattern and direction were kept constant in hand-centred space across both orientation conditions (i.e., hands were always stroked from knuckle to fingertip).

At the beginning of each condition block, participants received an initial embodiment induction. This consisted of 6 repetitions of the stroking pattern and lasted approximately 1.5 minutes (60 strokes in total). Regular embodiment stimulation updates occurred during each block, appearing after every 15 task trials. Each update-trial consisted of one instance of the stroking pattern (10 strokes) and lasted 12 seconds. There were 13 update-trials in total. For the initial embodiment induction and all subsequent updates, the experimenter always began the stroking pattern on the index and middle finger.

Proprioceptive drift measurement. Drift of perceived right-hand location toward or away from the plaster hand was measured using the haptic proprioception gauge. To operate the gauge, each participant was instructed to first close their eyes then indicate the elevation of their right hand. To do this, the participant had to grasp the clamp using their left hand and slide it down the beam until it was level with their right hand. To prevent any visual feedback on their performance, the participant kept their eyes closed while the experimenter recorded the measurement and reset the gauge. Measurements were taken before (initial) and after (post) each block, totalling four measurements per participant. Vertical proprioceptive drift (for either orientation condition) corresponded to a change in the reported elevation between the initial and post measurements. The time between initial and post measurements for one condition was approximately 20 minutes.

Task and trials. As in Experiment 1, an unspeeded two-interval forced-choice task was employed. However, only tactile-leading asynchronies were presented. Participants were asked to indicate in which interval (first or second) there was a delay between the visual and tactile stimuli. Participants were instructed that the

when there was asynchrony, the tactile stimulus would always precede the visual stimulus. For each trial, whether the asynchronous (target) presentation appeared in the first or second interval was pseudorandom, with an equal number of asynchronous presentations appearing in the first and second intervals. In Experiment 1, both visual-leading and tactile-leading asynchronies were presented. In Experiment 2, however, only tactile-leading asynchronies were presented. This could invite a temporal anchoring between the beginning of each trial (controlled by the participant) and the onset of the tactile stimulus. This redundant temporal information could confound the results of Experiment 2. Hence, to avoid temporal cuing the inter-trial gap varied randomly between 800-1200 ms. The gap between the first and second interval also varied randomly between 800-1200 ms.

Participants completed each orientation condition in a separate block. For the duration of the block, participants viewed the plaster hand in either a plausible or implausible orientation. The order of condition blocks (first block plausible, second block plausible) was counterbalanced across participants.

Before the experiment, participants practiced the 2IFC task for 20 trials, and were given feedback on their performance. The practice trials involved longer SOAs (300 ms) to minimise practice effects. No plaster hand was on the top of the experimental box during the practice trials. Before the experiment, the participant removed any jewellery (e.g., rings, watches, bracelets) from their right hand.

Each condition block consisted of 210 trials (30 trials for each of 7 SOAs), amounting to 420 trials in total for each participant. Participants took breaks between condition blocks and received no feedback on their performance in experimental trials. The room was dimmed during the experimental task. Proprioceptive drift measurements were taken before and after each condition block. After each block, following the second proprioceptive drift measurement for that condition, the participant filled out an embodiment questionnaire for the orientation condition corresponding to the just-completed block. Question order was randomised each time. The entire experimental session took approximately one hour to complete.

3.1.5 Data analysis

This experiment used the same data analysis protocols and exclusion criteria as Experiment 1. However, given that participants in this experiment only detected

tactile-leading asynchrony, the results present two fitted functions per participant, one for each orientation condition.

3.2 Results

3.2.1 Exclusions

For Experiment 2, there were no failed fits. Data from 5 participants were removed because either one or both fits were unacceptably poor. One participant was an outlier, and their data therefore removed. After exclusions, 25 participants (mean age = 23 years, SD = 8.4 years, 14 female) were included in the analysis.

3.2.2 Rubber hand illusion

Proprioceptive drift. Figure 3.3 depicts mean proprioceptive drift for both orientation conditions. A paired t-test indicated that proprioceptive drift toward the plaster hand was significantly larger in the plausible ($M \pm \text{SEM} = 20 \text{ mm} \pm 13 \text{ mm}$) than in the implausible ($M \pm \text{SEM} = -10 \text{ mm} \pm 10 \text{ mm}$) orientation condition (mean difference = 30 mm, $t(24) = 2.23$, $p = .036$, Cohen's $d = 0.52$).

The proprioceptive drift measure for each condition depended on the difference between two figures, the *initial* measurement and the *post*-condition measurement. Hence, if participants systematically differed in their initial proprioceptive measurement for the plausible and implausible conditions, this could bias the difference in proprioceptive drift between conditions. However, a paired t-test revealed no significant difference in mean *initial* measurements between plausible ($M \pm \text{SEM} = 104 \text{ mm} \pm 10 \text{ mm}$) and implausible ($M \pm \text{SEM} = 108 \text{ mm} \pm 7 \text{ mm}$) orientation conditions (mean difference = 4 mm, $t(24) = 0.49$, $p = .63$, Cohen's $d = 0.1$). Rather, there was a significant correlation between *initial* measurements from the plausible and implausible condition blocks (Pearson's $r(25) = .53$, $p = .006$), suggesting that participants were consistent in their initial judgments between orientation conditions.

Embodiment questionnaire. I tested the rating scale means for normal distributions because the questionnaire data could potentially be skewed. I found evidence for a non-normal distribution in the mean questionnaire ratings for the implausible orientation condition (Shapiro-Wilk test, $p = .049$). Thus, the normality assumption

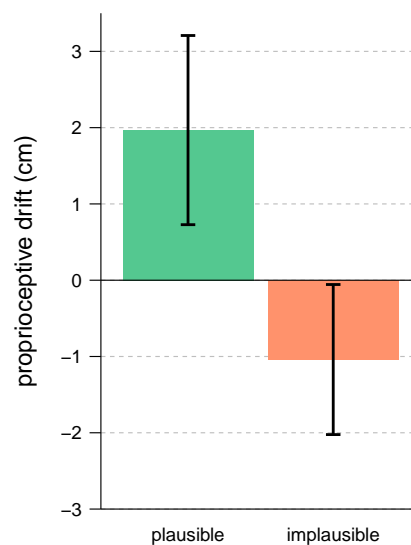


Figure 3.3: Mean vertical proprioceptive drift. Positive drift figures represent a drift of perceived right hand location towards the plaster hand. Negative figures represent a drift away from the plaster hand. The plaster hand was located on a surface 125 mm above the participant's real hand. Error bars represent the SEM.

was challenged and I conducted a non-parametric paired comparison of questionnaire data. A Wilcoxon Signed-ranks test indicated that mean levels of agreement with the questionnaire items were significantly higher in the plausible condition ($M \pm \text{SEM} = 5.7 \pm 0.2$) than the implausible condition ($M \pm \text{SEM} = 3.1 \pm 0.3$), $Z(24) = 4.293, p < .001$, Cohen's $d = 1.5$.

Correlations between illusion measurements. To measure whether the proprioceptive drift and embodiment illusion scores offered comparable measures of the rubber hand illusion, I examined the correlation between measures. There was a significant correlation between magnitude of proprioceptive drift (plausible drift – implausible drift) and questionnaire score (plausible score – implausible score), indicating that the manipulation between plausible and implausible orientation conditions changed both subjective and behavioural aspects of body perception (Pearson's $r(25) = .62, p = .001$).

3.2.3 Asynchrony detection thresholds

A paired t-test revealed no significant difference in mean asynchrony detection performance between plausible ($M \pm \text{SEM} = 171 \text{ ms} \pm 21 \text{ ms}$) and implausible ($M \pm \text{SEM} = 168 \text{ ms} \pm 17 \text{ ms}$) orientation conditions (mean difference = 3 ms,

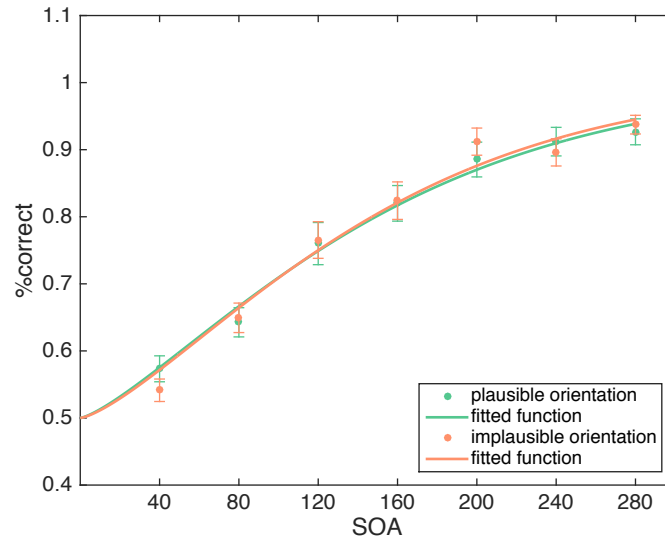


Figure 3.4: Mean proportion of correct responses for all SOAs in Experiment 2. A Weibull function is fitted to the mean group responses for demonstrative purposes only; estimations of asynchrony detection thresholds were calculated on an individual basis. Error bars represent the SEM.

$t(24) = 0.37$, $p = .71$, Cohen's $d = 0.03$). Figure 3.4 depicts the group mean proportion of times participants correctly identified the interval which presented the (tactile-leading) delay for the range of SOAs for each orientation condition. As can be seen in this figure, the mean proportions across the SOAs were quite similar between the two orientation conditions.

Comparison of Psychometric function data: slope and goodness-of-fit. A paired t-test also revealed no significant difference in mean slope between plausible ($M \pm \text{SEM} = 1.88 \pm 0.19$) and implausible ($M \pm \text{SEM} = 1.79 \pm 0.14$) orientation conditions (mean difference = 0.08, $t(24) = 0.41$, $p = .69$, Cohen's $d = 0.10$). Further, there was no significant difference in Dev between plausible ($M \pm \text{SEM} = 5.30 \pm 0.58$) and implausible ($M \pm \text{SEM} = 5.31 \pm 0.54$) orientation conditions (mean difference = 0.01, $t(24) = 0.02$, $p = .98$, Cohen's $d = 0.005$).

Correlations. To test if there was an association between changes to body perception and visual-tactile asynchrony perception, I examined the correlation between embodiment measures and detection thresholds. There was no significant correlation between the magnitude of proprioceptive drift (plausible drift – implausible drift) and the difference in asynchrony detection threshold between plausible and implausible conditions (Pearson's $r(25) = .02$, $p = .92$). There was also no significant correlation between the magnitude of questionnaire score (plausible score –

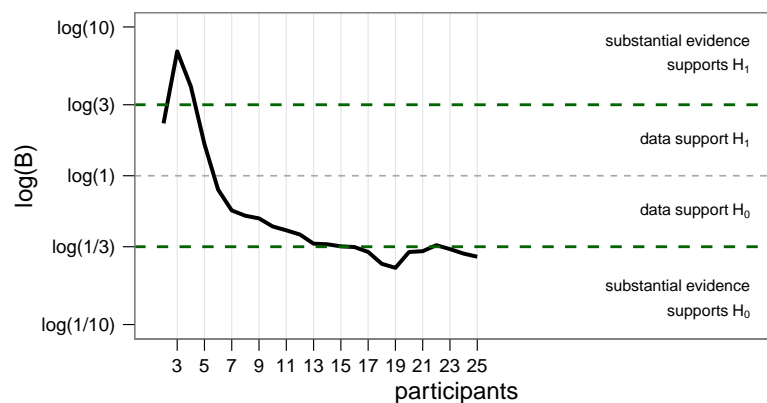


Figure 3.5: Iterative Bayes factor calculations for tactile-leading asynchrony detection thresholds.

implausible score) and the difference in asynchrony detection threshold between plausible and implausible conditions (Pearson's $r(25) = -.05, p = .81$).

3.2.4 Bayesian analysis of asynchrony detection performance

Using the same priors as delineated in Experiment 1, I calculated B for the difference in asynchrony detection threshold in Experiment 2. Figure 3.5 shows the iterative calculations of B . At $N = 25$, $B = 0.29$. A B of less than $1/3$ is taken to indicate strong evidence for the null hypothesis (Dienes, 2011, 2014; Ling, Li, Qiao, Guo, & Dienes, 2016; Ziori & Dienes, 2015). Whereas the non-significant p -value cannot give evidence in support of the null hypothesis, this calculation B gives strong reason to support the null hypothesis over the alternative hypothesis (Jeffreys, 1939).

3.3 Discussion

In this experiment, I investigated the influence of multisensory bodily-self information on the precision of visual-tactile asynchrony detection. I manipulated the plausibility of visual information for hand ownership and measured the proportion of correct asynchrony judgments for a variety of SOAs, deriving thresholds for asynchrony detection as a measure of performance. The dependent variable was the difference in asynchrony detection performance between plausible and

implausible hand orientation conditions for tactile-leading asynchrony.

To induce illusory experiences of embodiment for the plausible bodily-self cue condition, participants received synchronous multisensory stimulation. Significant differences in questionnaire score and proprioceptive drift between orientation conditions suggests that the manipulation of bodily-self cues led to the RHI. I also examined the correlation between questionnaire score results and the proprioceptive drift measure, and found it to be significant. This suggested that the plausibility of bodily-self cues used here affected both subjective and behavioural aspects of body representation.

I hypothesised that the plausible bodily-self cues would increase sensitivity to visual-tactile asynchrony. Frequentist analysis of the data revealed no significant difference in asynchrony detection performance between the plausible and implausible orientation conditions for tactile-leading asynchronies. There were also no significant differences in slope between the orientation conditions, suggesting that there was no difference in contrast precision for either orientation condition. Furthermore, there were no significant differences in goodness-of-fit for the psychometric functions between the orientation conditions, suggesting that neither orientation condition yielded more accurate performance measures.

A Bayesian analysis revealed that the detection threshold data were not too insensitive to reveal an effect. Rather, the experimental findings strongly support the null hypothesis, as the *Bayes factor* was less than 1/3. From here I conclude that the manipulation of multisensory bodily-self cues does not increase visual-tactile asynchrony detection precision.

I also looked at correlations between both measures of embodiment change and the difference in asynchrony detection performance to test if participants who felt the illusion more strongly differed more in their performance between conditions. There were no significant correlations.

Experiment 1 revealed that visual bodily-self cues did not increase precision of visual-tactile asynchrony detection. However, the paradigm in Experiment 1 lacked stronger multisensory bodily-self cues, present in studies finding an effect of bodily-self cues on visual-proprioceptive perception (Hoover & Harris, 2012, 2015; Zopf et al., 2015). These multisensory cues might have been critical for the effect. Therefore, in Experiment 2, I incorporated stronger, multisensory bodily-self cues, and found that these also did not increase precision of visual-tactile asyn-

chrony detection. Hence, the results from Experiment 1 cannot be explained by the minimal bodily-self cues.

4 General Discussion

Two aims motivated the present study. First, the study aimed to examine whether bodily-self cues affect the precision of visual-tactile temporal processing, similarly to how bodily-self cues affect visual-proprioceptive temporal processing. Second, the study aimed to see whether such an effect could arise from visual bodily-self information (as examined in Experiment 1), or the combination of visual and multisensory bodily-self cues (as examined in Experiment 2). Such stimulation is known to change the representation of one's own body and induce the rubber hand illusion. In two experimental paradigms, I presented different bodily-self cues and used a two-interval forced-choice (2IFC) task to measure the threshold for visual-tactile asynchrony detection. In the following discussion, I summarise the experimental findings and discuss the theoretical implications of this work. I then consider the limitations of measures for embodiment manipulations, and suggest how future work can address some of the open questions that still remain.

4.1 Overview of the present study

In Experiment 1, I compared the threshold for visual-tactile asynchrony detection for anatomically plausible and implausible hand orientations. Using a frequentist analysis, I found no significant effect of plausible visual bodily-self cues on the precision of visual-tactile asynchrony detection, for either visual-leading or tactile-leading asynchrony. Further, a comparison of psychometric function slope revealed no difference in contrast precision between the conditions.

As there is no way to distinguish between a true null finding (there is no effect) and a lack of sensitivity (a lack of power to discover the effect) with frequentist statistics, I conducted an additional analysis on the effect of interest. By calculating Bayes factors, I could test the strength of the alternative hypothesis against

the null hypothesis *given the experimental evidence*. My original alternative hypothesis predicted that visually plausible bodily-self cues would increase the precision of visual-tactile asynchrony detection compared to visually implausible cues. The Bayesian analysis showed that the experimental data provided evidence against this hypothesis. From the first experiment, I concluded that visual bodily-self information does not increase visual-tactile asynchrony detection precision.

The bodily-self cues presented in Experiment 1 might not have been strong enough to affect visual-tactile temporal processing. So, in Experiment 2 I examined the effect of stronger bodily-self cues on visual-tactile temporal processing. In Experiment 2, I compared the threshold for visual-tactile asynchrony detection for plausible and implausible multisensory bodily-self cues. As in Experiment 1, the plausible and implausible bodily-self conditions differed in the plausibility of viewed hand orientation. However, in Experiment 2, participants felt synchronous visual-tactile stimulation as an additional bodily-self cue. Using a frequentist analysis, I found no significant effect of bodily-self cues on the precision of visual-tactile asynchrony detection, for tactile-leading asynchrony. As in Experiment 1, I also performed a Bayesian analysis of these data, testing the strength of the alternative hypothesis against the null hypothesis *given the experimental evidence* from Experiment 2. The Bayesian analysis showed strong support for the null hypothesis. From the second experiment, I concluded that the results of Experiment 1 cannot be due to the lack of strong bodily-self cues, and further that multisensory bodily-self cues do not increase visual-tactile asynchrony detection for tactile-leading asynchrony.

In Experiments 1 and 2, I used a standard questionnaire to assess changes to embodiment between experimental conditions. As a concurrent measure of embodiment changes, I also measured proprioceptive drift in Experiment 2. Significant differences in questionnaire and proprioceptive drift between plausible and implausible conditions in Experiment 2 suggest that the manipulations of bodily-self cues successfully induced the rubber hand illusion (RHI). Further, the magnitude of these two measures were significantly correlated. The manipulations of bodily-self cues in Experiment 1, however, were not designed to induce the RHI. Surprisingly, I also found a significant difference in questionnaire results between plausible and implausible conditions in Experiment 1. For both experiments, I also looked at correlations between all measures of embodiment change

and the difference in asynchrony detection performance to test if participants who felt the illusion more strongly differed more in their performance between conditions. There were no significant correlations.

4.2 Do bodily-self cues have a general effect on the perception of multisensory timing?

The current findings provide no support for the hypothesis that we make sensory predictions about bodily-self stimuli that improve our temporal processing of multisensory stimuli (Zopf et al., 2015). This account holds that visual hand information should influence synchrony perception for multisensory events that are highly correlated in own-body contexts, based on previous studies of visual-proprioceptive asynchrony detection (Hoover & Harris, 2012, 2015; Zopf et al., 2015). Like visual-proprioceptive events, synchronous visual-tactile events are also highly correlated with bodily-self information. Here, though, I found no evidence that bodily-self cues improve asynchrony detection of visual-tactile stimuli. Rather, by using Bayesian analyses, I found clear evidence that there is no effect. We therefore need to look for potential alternative explanations for the combined findings of the current study and the previous literature.

The results of my study suggest that the effect of bodily-self information on visual-proprioceptive temporal processing does not generalise to visual-tactile processing. Some key aspects of visual-proprioceptive processing might explain the difference from visual-tactile processing. First, visual-proprioceptive events are associated with efferent and afferent information: this additional information involved in active movement may allow for stronger sensory predictions in visual-proprioceptive events than in visual-tactile events. This would mean small asynchronies in visual-proprioceptive stimuli would violate sensory predictions, and would be more salient than visual-tactile asynchronies. This could explain the increased sensitivity to visual-proprioceptive mismatches in own-body contexts. However, one study suggests that the presence of efferent signals does not increase the precision of visual delay detection: Shimada, Qi, and Hiraki (2010) found no significant difference in visual-proprioceptive delay detection thresholds between active and passive movement conditions. Hence, the mere presence of efferent information in the paradigms used by Hoover and Harris (2012, 2015)

and Zopf et al. (2015) might not explain the different findings between their visual-proprioceptive studies and my own.

Stimuli in the visual-proprioceptive studies and this visual-tactile study also differ in their predictive content. The visual-proprioceptive stimuli featured in self-generated movements are highly associated in ordinary situations. However, the visual-tactile stimuli featured in my study—the tap and the light—are not naturally associated with each other. In this regard, the multisensory stimuli used by Hoover and Harris (2012, 2015) and Zopf et al. (2015) are more predictive than the stimuli used in my study. The interaction of bodily-self cues with multisensory temporal processing might critically depend on the predictive content of the stimuli (Kandula, Hofman, & Dijkerman, 2015). However, this difference is not specific to bodily-self information, and hence might be a confound for the claim that bodily-self cues underlie modulations to multisensory temporal processing. If the predictive qualities of the experimental visual-proprioceptive stimuli underlie modulated multisensory processing, then specifically bodily-self information might not directly affect temporal comparison of multisensory stimuli. This study specifically tested this hypothesis—whether bodily-self cues directly affect temporal processing of multisensory stimuli—and showed compelling evidence that they do not for visual-tactile stimuli. This result means that a possible alternative explanation for the findings of Hoover and Harris (2012, 2015) and Zopf et al. (2015) might critically depend on other predictive qualities of the experimental stimuli.

Visual processing of bodily-self cues might also involve special perceptual mechanisms for perceiving biological movement. One study suggests that such mechanisms could affect multisensory temporal processing when biological movement is involved: Saygin, Driver, and de Sa (2008) found that thresholds for audio-visual asynchrony were smaller for biologically familiar movements than for unfamiliar movements. Importantly, the effect of biologically plausible information on multisensory temporal processing they found did not involve bodily-self cues. The paradigms used by Hoover and Harris (2012, 2015) and Zopf et al. (2015) also feature biological hand movement in their visual stimuli. This feature might be a critical difference between visual-proprioceptive and visual-tactile temporal processing, and could explain why bodily-self cues affect visual-proprioceptive temporal processing, but not visual-tactile temporal processing. However, little is

known about the processing of biological movement in own-body contexts, and if, for example, movements are faster detected for plausible than implausible hand orientations. Hence, more research is needed before such claims can be made.

In sum, several factors differ between the visual-tactile and visual-proprioceptive studies described here. Compared to visual-tactile stimuli, visual-proprioceptive stimuli are associated with efference copy, biological movement, and in some situations, further predictive information. These might explain the discrepancy between the findings of my study and other similar paradigms. From the present study, I conclude that there is not a general effect of bodily-self cues on multisensory temporal processing. Instead, the effect of bodily-self cues on visual-proprioceptive temporal processing might depend on strongly predictive stimuli, or perhaps there is a unique effect of bodily-self cues on the temporal comparison of particular multisensory stimuli, but not visual-tactile stimuli. Future experiments could further test the interaction between highly predictive multisensory stimuli, bodily-self cues, and the precision of multisensory temporal processing. A better understanding of these factors offers potential explanations of the diverse phenomena associated with multisensory body representations.

4.3 How could bodily-self cues modulate visual-tactile processing?

In the current study, I found no effect of bodily-self cues on visual-tactile temporal processing. The analyses revealed no differences in sensitivity (indicated by a change in detection threshold) or contrast precision (indicated by a change in psychometric function slope) to visual-tactile asynchrony. However, other tasks have demonstrated effects of bodily-self cues on visual-tactile processing (Igarashi et al., 2004; Pavani et al., 2000; Wada & Ide, 2016; Zopf et al., 2010). Although these studies give compelling evidence for the interaction of multisensory information in bodily-self contexts, they do not directly examine the effects of bodily-self information on visual-tactile *temporal* processing. Instead, crossmodal congruency tasks show that visual bodily-self cues can affect the interference of visual distractors on the localisation of touch. One explanation of this suggests that bodily-self cues cause spatial remapping of multisensory space, moving targets closer to distractors (Pavani et al., 2000). Zopf et al. (2010) suggest that bodily-self cues modify

our representation of near-body space. Spatial modulation of multisensory processing in own-body contexts might feasibly explain the findings in the previous literature. The findings of my study are compatible with this notion—if bodily-self cues have no effect on the temporal precision of visual-tactile perception, then bodily-self cues might affect visual-tactile processing only in the spatial domain.

The results of the frequentist threshold comparison in both Experiments 1 and 2 seem to contradict the explanation and predictions described by Ide and Hidaka (2013). Their study directly investigated the effect of visual hand orientation on visual-tactile temporal order judgments, finding that the JND between visual and tactile stimuli increased when participants viewed the image of an upright hand compared with viewing an upside-down hand image. Their results suggest that the precision of visual-tactile temporal perception is worse for plausible bodily-self stimuli than for implausible bodily-self stimuli. To explain this result, Ide and Hidaka (2013) claim that visual bodily-self cues cause visual and tactile stimuli to be perceptually grouped, diminishing the ability to perceive small temporal asynchronies between the stimuli. Such a mechanism would also predict a significant increase in asynchrony detection thresholds in the plausible orientation conditions over the implausible orientation conditions. Neither Experiments 1 or 2 revealed this pattern. This pattern of results would be even more likely in my study, as these experiments employed more realistic hand stimuli (high-relief model hands) than the line drawings used by Ide and Hidaka (2013). Given the clear predictions of their theory, and the strength of the current evidence, it is likely that an alternative explanation is required to explain the results of Ide and Hidaka (2013).

If perceptual grouping does not explain the findings of Ide and Hidaka (2013), what might explain their findings and the difference from the current study? First, whereas the current study used a 2IFC synchrony judgment (SJ) task, Ide and Hidaka (2013) used a temporal order judgment task. There is no correlation between performance on SJ and TOJ tasks for audio-visual stimuli, suggesting that SJ and TOJ tasks may involve different perceptual mechanisms (Love et al., 2013). This means that body context could affect one mechanism and not the other. Alternatively, participants might be able to perceive asynchrony without perceiving temporal order, making TOJ tasks more difficult than SJ tasks (Vroomen & Keetels, 2010). Body context might only affect performance in the more perceptually difficult task. Thus, the difference between my results and those of Ide and Hidaka

(2013) could be an artefact of the temporal order judgment paradigm.

Another key difference between my study and the paradigm used by Ide and Hidaka (2013) is the spatial disparity between the visual and tactile stimuli. Increasing the spatial discrepancy between visual and tactile stimuli increases temporal order judgment precision (Spence et al., 2003). This is because spatial position could serve as a redundant cue. To reduce the effect of redundant spatial cues on task performance, the experimental paradigms employed in the present study kept the distance between visual and tactile stimuli to a minimum. In their experimental paradigm, Ide and Hidaka (2013) presented tactile stimuli on participants' hands, and visual stimuli on a monitor in front of participants, meaning visual and tactile stimuli were spatially more separate. While the spatial disparity between visual and tactile stimuli remained constant in objective space between hand orientation conditions, the plausible hand orientation condition was blocked, potentially allowing for changes to the body representation and associated changes to multisensory space. Given the spatial disparity between participants' real hands and the hand image, proprioceptive drift toward the hand image could have allowed for remapping of tactile space. If this notion is correct, participants would perceive the visual and tactile stimuli to be closer in subjective space for the plausible hand orientation condition than for the other orientation conditions, which would selectively degrade temporal order judgment precision in the plausible hand orientation condition, if spatial difference served as a redundant cue. In contrast, if any spatial remapping occurred in the current Experiments 1 or 2, any introduced spatial discrepancy would be minor, given that the visual and tactile stimuli were already close together in objective space. Considering both the differences between the experimental paradigms, and the potentially conflicting results, it is worth examining the paradigm used by Ide and Hidaka (2013), with a higher-powered design (twelve participants comprised their original study). A further modification of the TOJ paradigm—one that manipulated the spatial disparity between stimuli—would allow us to test the potential differences between their study and the present study.

4.4 Limitations of embodiment measures

In order to reduce experiences of illusory embodiment, Experiment 1 interleaved plausible and implausible orientation condition trials. Despite using standard methods to minimise changes to body representation, the questionnaires showed evidence of the rubber hand illusion for the plausible orientation condition. It is possible that visual plausible orientation information did result in the RHI. Alternatively, the results might reflect a limitation of standard questionnaire measures. The standard questionnaire items potentially invite participants to compare the plausible and implausible conditions, intensifying the magnitude of the differences reported. This could artificially enhance any differences between conditions. If this notion is correct, it raises questions about the validity of using questionnaires alone to measure changes to body representation. Further, if participants base their responses on a comparison of conditions, then this diminishes the efficacy of the results as *independent* measures of subjective experience.

I set the parameters in Experiment 2 to deliberately induce the RHI. Specifically, the plausible orientation trials were blocked, and participants felt synchronous multisensory stimulation. I also included proprioceptive drift measures as well as questionnaires. Holle et al. (2011) have raised concerns about proprioceptive drift as a measure of RHI, as it may occur in the absence of illusory experience (as indicated by questionnaires). However, in Experiment 2 I found a significant correlation between the two measures. Other studies have also shown a similar relationship between these subjective and objective measures of body perception in RHI paradigms (Botvinick & Cohen, 1998; Longo, Schüür, et al., 2008). Still, the relationship between the measures is not clearly understood. Despite this, the significant differences in both proprioceptive drift and questionnaire score between orientation conditions indicate the the manipulations in Experiment 2 changed both subjective and behavioural aspects of body representation. In future research, the relationship between the measures could be studies in more detail.

4.5 Summary and Conclusions

This study set out to investigate interactions between own-body contexts and visual-tactile temporal processing. Using a 2IFC task, I measured the difference in thresholds for visual-tactile asynchrony perception between plausible (viewing hands for which fingers are oriented away from the body) and implausible (viewing hands for which fingers are pointing towards own body) own-body contexts. I found no difference in detection thresholds between plausible and implausible bodily-self cues (purely visual and multisensory). In contrast, the current findings provide compelling evidence that bodily-self cues do not alter the precision of visual-tactile asynchrony detection. Previous studies found modulations of temporal visual-proprioceptive processing in own-body contexts (Hoover & Harris, 2012, 2015; Zopf et al., 2015). The findings from my study suggest that this effect is not the result of a general increase in temporal precision for synchronous multisensory stimuli in own-body contexts. Rather, these findings suggest that visual-proprioceptive synchrony perception in own-body contexts is a special case of dynamic multisensory processing. Future research is required to better understand the informational differences between visual-tactile and visual-proprioceptive processing in own-body contexts.

The results of my study have also implications for the interpretation of previous research on bodily-self modulations of visual-tactile processing. Previous research employing the crossmodal congruency task and temporal order judgements found effects of body-self cues on visual-tactile processing (Pavani et al., 2000; Zopf et al., 2010). These effects could be explained by modulations of spatial body perception. In other words, my results in combination with the previous findings suggest that bodily-self cues can affect visual-tactile *spatial*, but not visual-tactile *temporal* processing. Future studies need to directly investigate the role of spatial and temporal information in multisensory bodily-self cue processing. A clearer picture of this interaction is especially important, not only for our understanding of healthy individuals, but also for our understanding of clinical populations who demonstrate abnormal processing of multisensory and bodily-self information.

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Appendix A Experiment 1 hand stimulus

The photograph below depicts one of the two identical model hands used in Experiment 1. Each model hand was a plaster casting from the same high-detail (25 micron-accurate alginate) mould of an adult male right hand. A piece of black cloth covered the wrist of each hand, so participants could not see the cut edge during the experimental trials. Scale increments are one centimetre.



Appendix B Experiment 2 hand stimulus

The photographs below depict the model hand used in Experiment 2. The model hand was a plaster casting from a high-detail (25 micron-accurate alginate) mould of an adult male right hand. A piece of black cloth covered the wrist of the plaster hand, so participants could not see the cut edge during the experimental trials. Scale increments are one centimetre.







Appendix C Ethics Approval

Office of the Deputy Vice-Chancellor (Research)

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MACQUARIE
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15 July 2015

Dr. Regine Zopf
Faculty of Human Sciences
Department of Cognitive Science
Macquarie University
NSW 2109

Dear Dr. Zopf

Reference No: 5201200558

Title: *Body Representations, Multisensory Perception and Action – Behavioural and fMRI Investigation.*

Thank you for your correspondence dated 2 July 2015 submitting an amendment request to the above study. Your proposed amendment was reviewed and approved by the HREC (Human Sciences & Humanities) Executive at its meeting held on 14/07/2015.

I am pleased to advise that ethical approval of the following amendments to the above study has been granted:

1. The addition of new personnel:
A/Professor Anina Rich and Mr Robert Keys.
2. The addition of the following method: IQ testing.
3. Amendments to the Information and Consent Form.
4. Including information about Oculus Rift on the Information and Consent Forms.

The HREC (Human Sciences and Humanities) 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

Please do not hesitate to contact the Ethics Secretariat should you have any questions regarding your ethics application.

The HREC (Human Sciences and Humanities) wishes you every success in your research.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Ma Shute'.

Dr Karolyn White

Director, Research Ethics & Integrity

Chair, Human Research Ethics Committee (Human Sciences and Humanities)

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) (the National Statement) and the CPMP/ICH Note for Guidance on Good Clinical Practice.

The following documentation submitted with your email correspondence has been reviewed and approved by the HREC (Human Sciences & Humanities):

Documents reviewed	Version no.	Date
Macquarie University HREC Request for Amendment Form	2.0	Received
Participant Information & Consent Form	6.0	1/07/15