Pain Observation, Empathy, and the Sensorimotor System: Behavioural and Neurophysiological Explorations

Pain Observation, Empathy, and the Sensorimotor System: Behavioural and Neurophysiological Explorations

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Lay Abstract

Past research suggests that overlapping brain activity during the first-hand experience of pain and pain observation may be indicative of empathy. However, very little work has been done to explore how pain observation influences overt behaviours. This thesis investigates this issue by having participants complete a reaction time task while watching videos of needles stabbing a person's hand. The findings reported in this thesis suggests that observing another in pain facilitates motor behaviours (i.e., faster reaction times); this facilitation extends 500ms after pain observation, affects both the hand and feet, is accentuated by instructing participants to explicitly empathize, and is not influenced by approach vs. withdraw movements. Brain activity in the motor system was also found to increase during pain observation. Overall, this thesis begins the discussion of how empathic pain observation influences explicit motor behaviours, and how such behaviours may be related to brain activity.

Abstract

Previous research has established that observing another in pain activates both affective and sensorimotor cortical activity that is also present during the first-hand experience of pain. Some researchers have taken this "mirroring" response as indicative of empathic processing. However, very little work has explored the downstream behavioral effects of empathic pain observation. The aim of this dissertation is to begin to fill this gap in the literature by exploring the relationship between empathic pain observation, overt motor behaviours, and sensorimotor activity. In chapters 2-4, I provide robust evidence that observing pain inflicted on another person leads to faster reaction time responses. This effect is shown to be temporally extended (by at least 500ms after pain observation), effector-general (affecting both finger and foot responses), influenced by top-down (i.e., instructions to explicitly empathize) but not bottom-up (i.e., the perceived level of pain) factors, and is not influenced by adaptive (approach/withdraw) behaviours. In chapter 5, I show that sensorimotor activity, measured via TMS-induced Motor Evoked Potentials, increases while observing another in pain regardless whether the observer is preparing to make an action vs. passively observing the stimuli. These results run counter to the literature, and I provide several explanations for why these results were found. Lastly, in chapter 6, I show that sensorimotor activity, measured via Mu and Beta suppression, also increases while observing another in pain regardless whether the observer is preparing to make an action vs. passively observing the stimuli. Interestingly, I do not find significant correlations between sensorimotor activity during pain observation and faster reaction times after pain observation. I embed these findings in relation to the wider social neuroscience of empathy literature and discuss several limitations and challenges in empirically measuring "empathy" as a psychological construct. Overall, this dissertation furthers our understanding of empathy for pain by highlighting the behavioural consequences of pain observation and its connection (or rather, lack thereof) to sensorimotor activity during pain observation.

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Declaration of Authorship

I, Carl Michael Galang, declare that this thesis titled, "Pain Observation, Empathy, and the Sensorimotor System: Behavioural and Neurophysiological Explorations", and the work presented in it are my own. The thesis consists of a general introduction, five empirical chapters, and a general discussion. Two out of the five chapters are published in peer-reviewed scientific journals. I am the primary author of all seven chapters. I conceptualized and designed each experiment in consultation with my supervisor, Dr. Sukhvinder S. Obhi. For each study, I was the primary individual responsible for creating stimuli, collecting data, supervising data collection by undergraduate students, analyzing the data, and preparing the manuscripts. The LATEX typeset of this thesis follows the McMaster Thesis Example by Benjamin Furman, license: CC BY-NC-SA 3.0. (https://github.com/benjaminfurman/`McMaster_Thesis_Template`).

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Chapter 1

General Introduction

1.1 Introduction

In the broadest sense of the word, empathy refers to the ability to share and understand the emotional state of others; this colloquial understanding of empathy is aptly captured by a well-known line in Alexander Pope's translation of Homer's Odyssey – "*Yet, taught by time, my heart has learn'd to glow. For others' good, and melt at others' woe*" (Book IVIII). Most researchers point to early work by David Hume (1711-1776) and Adam Smith (1723-1790) as the starting point of scholarly inquiry into the nature of empathy; however, it was not until the turn of the 20th century that the term "empathy" was coined and inserted into the English language (Coplan and Goldie, 2011). Derived from the German word Einfuhlung (which directly translates to "feeling into"), empathy is often considered a fundamental part of the human condition, so much so that a lack of empathic abilities is often considered morally repugnant (and even pathological in extreme cases). Given its inherent social and psychological nature, it should come as no surprise that psychologists of various stripes have taken keen interest in scientifically investigating empathy (for anthologies and reviews: Decety and Ickes, 2009; Coplan and Goldie, 2011). This is especially true in the emerging field of social cognitive neuroscience, which considers empathy to be one of its cornerstone topics (Lieberman, 2012).

The aim of this dissertation is to contribute to this growing field by providing novel

insights related to the role of overt motor behaviours and sensorimotor processes in empathy for pain. The subsequent sections of this introductory chapter lay the groundwork for these insights. In section 1.2, I describe how empathy is conceptualized in social cognitive neuroscience. In section 1.3, I summarize the role of sensorimotor activity on empathy for pain. In section 1.4, I discuss a major gap in the literature, namely the lack of data exploring the downstream behavioural consequences of such sensorimotor activity, and subsequently motivate the need to explore how empathy for pain influences overt motor behaviours. Lastly, section 1.5 provides a road map for how the subsequent chapters of this dissertation fill this gap in the literature.

1.2 The Perception-Action Model of Empathy

Social cognitive neuroscience research in the past two decades has made great strides in uncovering the neurobiological underpinnings of empathic processing (for recent reviews, see: Betti and Aglioti, 2016; De Waal and Preston, 2017; Heyes, 2018; Tremblay et al., 2018; Riečanský et al., 2019). Although there is no agreed upon definition of empathy in the field (e.g., Batson, 2009; Bernhardt and Singer, 2012), a dominant framework in social cognitive neuroscience is the Perception-Action Model of Empathy (PAM; Preston and De Waal, 2002; De Waal and Preston, 2017). PAM suggests that empathy arises as a result of the nervous system mapping the states of others onto itself. For example, if I observe another person fall while riding their bike, then PAM suggests that my perception of their particular state activates my own representations of that state (in addition to the context surrounding it) and automatically generates the associated autonomic and somatic responses (unless inhibited). These automatically generated responses then allow me to both share and understand what the other is experiencing. Other researchers simply refer to this as "affective state matching" (e.g., de Vignemont and Singer, 2006; Bird and Viding, 2014) and is considered a necessary, although not sufficient, condition for empathy.

In addition to affective state matching, another posited necessary condition for empathy is self-other distinction (e.g., de Vignemont and Singer, 2006; Bird and Viding, 2014). Self-other distinction (or self-other control) refers to one's ability to control neural/mental representations pertaining to the self vs. others (e.g., Brass et al., 2009). When self-other distinction is low, then there is a large overlap between the representations of the self and other, such that confusion regarding the source of a particular state can occur. When this happens, affective state matching may lead one to focus on oneself, which often leads to personal distress rather than an empathic response – this state is of often referred to as emotional contagion (e.g., Preston and De Waal, 2002; Singer and Lamm, 2009). When self-other distinction is high, then such confusion can be avoided; thus, the source of one's affective state will be apparent, and the focus can then be on the other rather than the self. Thus, affective state matching and self-other distinction are both necessary and together sufficient for empathy to arise.

1.3 Sensorimotor Resonance

Definitions aside, social cognitive neuroscientists have used a wide variety of tools to explore the neurobiological underpinnings of empathy (Neumann and Westbury, 2011). Such research has primarily focused on empathy for pain, as pain is a salient and ubiquitous phenomenon that is strongly (at least intuitively so) linked to empathic experiences (Tremblay et al., 2018). Research on pain empathy has shown overlapping neural activity in areas of the brain related to both the emotional (e.g., Singer et al., 2004; Jackson et al., 2005; Botvinick et al., 2005) and sensorimotor (e.g., Avenanti et al., 2005; Cheng et al., 2008; Lamm et al., 2011) components of nociception. This latter effect is sometimes referred to as "sensorimotor resonance" (e.g., Avenanti et al., 2010; Riečanský et al., 2015), with the term "resonance" referring to the overlapping neural activity between the subject and object of empathy. Although sensorimotor resonance can be explored

using a variety of different tools, two methods in particular have made strong contributions to our understanding of this topic: Transcranial Magnetic Stimulation (TMS) and Electroencephalography (EEG).

TMS is a neuromodulation tool that can stimulate cortical activity via electromagnetic waves; delivered over the motor cortex, TMS can elicit motor evoked potentials (MEPs) in corresponding muscles which can be measured via electromyography (EMG). Such measures are taken as an indication of corticospinal excitability at the time of stimulation[1]. In a seminal study, Avenanti et al. (2005) had their participants observe videos of a hand getting stabbed by a needle, touched by a Q-tip, or a needle stabbing a tomato. As they observed the videos, muscle activity was collected from their right hands in two locations: the first dorsal interosseous (FDI) and the abductor digiti minimi (ADM). Crucially, the needle/Q-tip targeted the FDI in the videos depicting a hand. Avenanti et al. (2005) found that there was a significant decrease in muscle activity during the "needle stabbing the hand" video compared to the Q-tip and tomato videos. Furthermore, this effect was specific to the FDI. Given that a muscle-specific decrease in motor activity is also observed during the first-hand experience of pain (e.g., Farina et al., 2001), Avenanti et al. (2005) concluded that "[...] *the effect may be due to activation of a pain resonance system that extracts basic sensory aspects of the model's painful experience (such as source or intensity of a noxious stimulus) and maps them onto the observer's motor system according to topographic rules*" (pg. 958). Note that this interpretation goes hand-in-hand with the PAM of empathy. Whether or not self-other distinction is occurring is an open question; however, given that participants were explicitly instructed to "imagine what the person is feeling", it is possible that self-other distinction was indeed occurring during the experiment.

While the original results of Avenanti et al. (2005) have generally been corroborated

[1]TMS is necessary when the phenomena of interest is not strong enough to be detectable via EMG alone. Furthermore, TMS stimulation ensures that the measures have a cortical origin.

and extended (e.g., Avenanti et al., 2006; Minio-Paluello et al., 2006; Fecteau et al., 2008; Avenanti et al., 2009a; Avenanti et al., 2009b; Avenanti et al., 2010; Mahayana et al., 2014; Bucchioni et al., 2016; De Coster et al., 2014; De Guzman et al., 2016), work using Mu (7-12Hz) and Beta (13-30Hz) desynchronization as an index of sensorimotor activity have found conflicting results. Using electroencephalography (EEG) or magnetoencephalography (MEG), electrical activity (or the produced magnetic fields) ostensibly coming from the brain can be measured via electrodes/sensory coils placed on/near the scalp. Such activity can be decomposed in the frequency domain to explore how different neural oscillatory patterns may be related to cognitive, emotional, and/or behavioural functions (e.g., Pfurtscheller and Lopes Da Silva, 1999). In a seminal study, Cheng et al. (2008) used MEG to record Mu oscillations while participants observed pictures of a person's hand or feet in painful vs. non-painful scenarios. They found stronger desynchronization during pain observation compared to the no pain condition, and as less Mu activity is related to an increase in somatosensory activity (Pfurtscheller and Lopes Da Silva, 1999), their results suggest that pain observation leads to an increase in somatosensory activity. Follow-up studies showed that Beta oscillations, which are related to an increase in motor activity (Pfurtscheller and Lopes Da Silva, 1999), also becomes desynchronized during pain observation vs. no pain (e.g., Riečanský et al., 2015; Riečanský et al., 2020; Grice-Jackson et al., 2017). As these results suggest that there is an increase in sensorimotor activity during pain observation, they are contrary to the TMS results which suggests that there is instead a decrease in sensorimotor activity.

Why this is the case is unclear; Riečanský and Lamm (2019) suggest that, given the differences in methods and measures (e.g., stimuli, region specificity, etc.), it is difficult to make direct comparisons between the two paradigms. It should also be noted that, as far as I am aware, there are no studies showing that Mu desynchronization occurs during the first-hand experience of pain; yet Beta desynchronization does seems to play a role during the first-hand experience of pain, specifically in regards to preparing a protective

action (Hauck et al., 2008). As such, previous research on Mu/Beta desynchronization only partially adheres to the PAM of empathy. Grice-Jackson et al. (2017), however, has recently shown that individual differences regarding feelings of vicarious pain modulate both Mu and Beta desynchronization during pain observation. Their data suggests that participants who showed the strongest vicarious pain tendencies (labelled as "sensory-localized responders") were the primary drivers in the overall Mu and Beta effects. As vicarious experiences lead to isomorphic affective states, these findings provide support for the proposal that such effects are indexing empathy. Whether participants are engaging in self-other distinction in these studies remains to be determined. Indeed, recent work by Riečanský et al. (2020) suggests that these effects are strongest when self-other distinction is low, thus suggesting that Mu and Beta desynchronization are perhaps indexing a type of emotional contagion rather than empathy *per se*.

1.4 From Pain Observation to Action

While future work will eventually resolve this methodological discrepancy (perhaps via the combination of TMS and EEG within a single study), this dissertation tackles another major gap in the literature: the lack of data exploring the downstream behavioural effects of pain observation and its connection to sensorimotor resonance. Sensorimotor activity does not occur for its own sake; as with other neural processes, such activity is often meant to elicit some type of action. This is also the case for painful experiences, wherein nociceptive signals functionally lead to adaptive behaviours to avoid further damage (e.g., Morrison et al., 2013). As such, to fully understand the functional role of sensorimotor activity during pain empathy requires knowledge of how such activity influences overt motor behaviour.

Although there has been little research in this area, a small number of relevant studies deserve mention. Early work by Morrison et al. (2007b) used reaction time paradigms to

explore how pain observation influences overt motor behaviours. In their first study, they had their participant observe videos of a needle or Q-tip stabbing/touching a person's finger tips. To measure motor behaviour, participants completed a Go/No-Go task with the video stimuli interleaved between each imperative cue. The imperative cue appeared either 100ms or 500ms after each video and participants responded to the onset of the imperative cue (or withheld their response on catch trials) with either a key press or release. The key press and release were meant to simulate approach-like (presses) and withdraw-like (releases) behaviours. They reported that participants produced slower reaction times for key presses after observing the needle pictures (compared to Q-tip), but faster reaction times for key releases after observing the needle pictures (compared to Q-tip). Interestingly, this effect only emerged when the imperative cue was shown 500ms after stimuli offset. They interpreted these results as suggesting that "[...] *visual social information about potential injury influences situation-appropriate behavioral responses*" (pg. 412) — slow approach and fast withdrawal are "situation-appropriate" responses to pain observation.

However, a subsequent study reported somewhat conflicting results. Morrison et al. (2007a) presented participants with pictures showing apparent motion of painful/-nonpainful items hitting/missing a person's hand. In this study, participants completed a Go/No-Go task; in one block, they pressed a key if they saw the item hit the hand and withheld their response if the item missed, in the other block, they responded to the misses and withheld their responses to the hits. Furthermore, all responses were made with key presses, rather than comparing key presses to key releases. Morrison et al. (2007a) reported that participants responded faster after observing pain-hit stimuli than after observing pain-miss, nonpain-hit, and non-pain miss stimuli. This result conflicts with the findings of Morrison et al. (2007b) in which key presses appeared to be slowed by pain observation.

This lowering of response times following pain observation seems to occur without

the need for any sort of temporal delay between the stimuli and response. However, methodological differences between the two experiments make comparisons difficult – both the stimuli and task instructions differed significantly across experiments. Morrison et al. (2007a) also recorded neural activity via fMRI during the task. They report that various areas (i.e., mid, dorsal anterior, and dorsal posterior) of the cingulate cortex showed significant activity specifically in the pain-hit condition. Furthermore, these results depended on the participant making a key press. As the cingulate cortex is involved in the emotional processing of painful experiences (Fabbro and Crescentini, 2014), these results provide the first evidence (of which I am aware) that links empathy-related neural processing with overt motor behaviours. However, as sensorimotor activity was not found in this study, the relationship between sensorimotor resonance and overt motor behaviours has yet to be explored.

In sum, there are conflicting results in studies that measure how overt motor behaviours are influenced by pain observation. Morrison et al. (2007b) report that adaptive behaviours (in the form of approach-like and withdraw-like movements) are elicited 500ms after pain observation, whereas Morrison et al. (2007a) report that general motor facilitation occurs immediately after pain observation. Furthermore, it remains unclear how the influence of pain observation on overt behaviours is related to sensorimotor resonance. The aim of this dissertation is to fill these gaps in the literature.

1.5 Outline of the Dissertation

This dissertation contains five data chapters. To start, chapter 2 presents a single experiment that explores how overt motor behaviours are influenced by pain observation. In contrast to Morrison et al. (2007b), but consistent with Morrison et al. (2007a), we found that keypresses were faster after observing another person in pain. Interestingly, this effect occurred regardless of whether the response was made with the participants'

right index finger or their foot, and regardless of whether the imperative cue to move was presented immediately after stimulus offset or 500ms after stimulus offset.

Chapter 3 corroborates the main results presented in chapter 2 and extends this research by exploring how bottom-up factors (perceived intensity of the observed pain) and top-down factors (instructions to explicitly empathize or to simply watch the pain stimuli), affect overt motor behaviours after pain observation. The results suggest that explicitly instructing participants to empathize leads to stronger motor facilitation after pain observation. However, we did not find evidence that the perceived intensity of the pain influenced motor behaviour.

Chapter 4 further extends this line of research by exploring how adaptive behavioural responses, in the form of approach-withdrawal movements, are influenced by pain observation. In contrast to Morrison et al.'s (2007b) original findings, we did not find such adaptive responses (using both key presses/releases and forward/backward movements on a joystick). Instead, we found a general motor facilitation effect of pain observation such that participants responses were relatively fast after pain observation regardless of movement type.

Whereas chapters 2, 3, and 4 focus on exploring the effects of pain observation on overt motor behaviours, chapters 5 and 6 focus on how overt motor behaviour, or preparation for overt motor behaviour, influences sensorimotor resonance. Chapter 5 combines TMS with a simple reaction time task. In one block, participants completed the TMS study while watching the stimuli passively, while in the other block, participants respond to an imperative cue (a square) which appeared immediately after stimuli offset. As such, the former block mimics a "normal" sensorimotor resonance study using TMS, while the latter block explores if/how preparing an action influences sensorimotor resonance. The results of Chapter 5 were surprising, as we did not replicate previous TMS results; instead, we found greater corticospinal activity after pain observation regardless

of block type. In addition, the behavioural result reported in previous chapters was not observed; however, this failure to replicate was probably due to the TMS stimulation influencing participants' keypresses during the experiment (as TMS stimulation will force muscle/finger twitches).

Chapter 6 closely matches chapter 5, however with EEG instead of TMS. The results of chapter 6, however, were consistent with previous EEG research – significant Mu and Beta desynchronization after pain observation. We also found that motor preparation did not influence these results. We did, however, find that participants response times were faster following pain observation (consistent with the chapters 2, 3, and 4), but did not find a significant correlation between reaction time effects and Mu/Beta.

Lastly, chapter 7 concludes this dissertation by summarizing the unique contributions and limitations of each chapter, discusses issues surrounding arousal levels and self-reported empathy, and suggests future avenues of research.

Chapter 2

Observing painful events in others leads to a temporally extended general response facilitation in the self

Galang, C.M., Naish, K.R., Arbabi, K., and Obhi, S.S. (2017). Observing painful events in others leads to a temporally extended general response facilitation in the self. *Experimental Brain Research, 235*(11), 3469-3477.

2.1 Preface

Given the conflicting results reported by Morrison et al. (2007b) and Morrison et al. (2007a), the current chapter introduces an experiment that attempts to answer the basic question: does pain observation facilitate or inhibit overt motor behaviours? To answer this question, participants completed a Go/No-Go task where the imperative cue to move (or withhold a response) were interleaved between pain and no-pain stimuli (matching Morrison et al., 2007b). However, participants responded exclusively with a keypress (matching Morrison et al., 2007a). The imperative cue either appeared immediately after the stimuli (matching Morrison et al., 2007a) or after a 500ms delay (matchingMorrison et al., 2007b). To better compare these results to those used in

the sensorimotor resonance literature, we obtained a video stimulus set used in previous TMS (e.g., Avenanti et al., 2010) and EEG (e.g., Riečanský et al., 2015) research. Lastly, as previous TMS research reported muscle-specific effects of pain observation, we had our participants either respond with their right index finger or foot; although this manipulation is not the same as muscle-specificity, we thought it analogous enough to include in the study.

The results of this experiment showed that pain observation elicited motor facilitation (faster response times), regardless of the temporal properties of the imperative cue and the effector used to make a response. As the responses were key presses, these results match Morrison et al. (2007a) but not Morrison et al. (2007b). Furthermore, these behavioural results run contrary to TMS research (which suggests that pain observation leads to a decrease of sensorimotor activity); however, they tend to match EEG research (which suggests that pain observation leads to an increase of sensorimotor activity). These results lay the groundwork for all subsequent chapters in this dissertation. Note that during this time in my education I was only aware of the TMS literature regarding sensorimotor resonance. As such, the introductory section of the chapter does not mention EEG research in regards to sensorimotor resonance.

2.2 Abstract

Excitability in the motor cortex is modulated when we observe other people receiving a painful stimulus (Avenanti et al., 2005). However, the task dependency of this modulation is not well understood, as different paradigms have yielded seemingly different results. Previous neurophysiological work employing transcranial magnetic stimulation (TMS) suggests that watching another person's hand being pierced by a needle leads to a muscle specific inhibition, assessed via motor evoked potentials. Results from previous behavioural studies suggest that overt behavioural responses are facilitated due to pain

observation (Morrison et al., 2007b; Morrison et al., 2007a). There are several paradigmatic differences both between typical TMS studies and behavioural studies, and within behavioural studies themselves, that limit our overall understanding of how pain observation affects the motor system. In the current study, we combine elements of typical TMS experimental designs in a behavioural assessment of how pain observation affects overt behavioural responding. Specifically, we examined the muscle specificity, timing, and direction of modulation of motor responses due to pain observation. To assess muscle specificity, we employed pain and non-pain videos from previous TMS studies in a Go/No-Go task in which participants responded by either pressing a key with their index finger or with their foot. To assess timing, we examined response times for Go signals presented at 0ms or 500ms after the video. Results indicate that observation of another individual receiving a painful stimulus leads to a non-effector specific, temporally extended response facilitation (e.g., finger and foot facilitation present at 0ms and 500ms delays), compared to observation of non-pain videos. This behavioural facilitation effect differs from the typical motor inhibition seen in TMS studies, and we argue that the effects of pain observation on the motor system are state-dependent, with different states induced via task instructions. We discuss our results in light of previous work on motor responses to pain observation.

2.3 Introduction

Observing or imagining another person in pain activates some of the same neural structures that are active during the first-person experience of pain (Singer et al., 2004; Jackson et al., 2005; Botvinick et al., 2005; Lamm et al., 2011). For example, Singer et al. (2004) found increased activity in areas such as the anterior cingulate cortex (ACC) and anterior insula (AI) both when participants personally experienced pain and when they imagined a close other in pain. Outside of fMRI studies, another method is the combined use of transcranial magnetic stimulation (TMS) and electromyography (EMG), which

allows researchers to assess activity in the motor system while participants perceive stimuli. TMS delivered over the motor cortex is used to elicit motor-evoked potentials (MEPs) in the corresponding muscles; these responses are taken as a measure of corticospinal excitability. In a seminal study by Avenanti et al. (2005), participants observed videos of a hand being either stabbed by a needle, or lightly touched by a Q-tip, while MEPs were recorded in specific muscles of the hand. Importantly, the videos showed the needle or Q-tip penetrating or touching the skin overlying the first dorsal interosseous (FDI) muscle of the hand, and MEPs were recorded both from this muscle and from a muscle in a remote part of the hand (the abductor digiti minimi). Measuring muscle activity at the moment the needle or Q-tip deeply penetrated or touched the hand, Avenanti et al. (2005) found that activity in the FDI was lower when participants viewed the needle penetrating the hand compared to when they saw the Q-tip touching the skin. This difference was not evident in the abductor digiti minimi (ADM), suggesting that the modulation was specific to the region that was penetrated/touched. Importantly, this MEP suppression effect is also observed when TMS is delivered after the painful event (De Guzman et al., 2016). In general, this suppression of motor activity during and after pain observation - sometimes termed "sensorimotor resonance" - is considered a neural 'mirroring' of activity that would occur if the observer were actually receiving the painful stimulus, since a similar decrease in muscle activity also occurs when an individual experiences pain first-hand (Farina et al., 2001).

Sensorimotor resonance is one possible mechanism by which we are able to empathize, or "feel with" others (Avenanti et al., 2005; Avenanti et al., 2006; Avenanti et al., 2009a; Betti and Aglioti, 2016; De Guzman et al., 2016). Bird and Viding (2014) proposed that empathising with another person requires two things: the ability to detect and experience another person's affective state, and the ability to attribute that state to the other person (rather than the self). Within this model of empathy, sensorimotor resonance would reflect the simulation of the other person's state by the observer. One explanation of how

sensorimotor resonance occurs is via the mirror neuron system. Although mirror neurons have been examined primarily in the context of action observation, it is possible that the motor activation characterising sensorimotor resonance develops in a similar way. Mirror neurons are cells that become active during both the observation and execution of the same action (Cook et al., 2014). One explanation of how these cells obtain this property is through associative learning over the course of development (e.g., Cook et al., 2014), as the perception and experience of certain movements are repeatedly paired. In the same way, sensorimotor resonance could be the result of accumulated experiences with sharp objects (e.g. receiving a shot while visiting a clinic) such that the sensory experience of seeing the needle pierce a body part becomes associated with the motor representations associated with experiencing the needle pierce that body part. When this association becomes strong enough, simply watching another person experience a sharp object might activate the observer's own motor representations.

To explore the functional significance of sensorimotor resonance, however, we must consider whether the suppression of motor cortical output evident in TMS studies is behaviourally significant. In a typical TMS study of pain perception, participants are instructed to remain still and keep their muscles relaxed while watching painful stimuli. Since this requirement to relax and maintain a constant position is not usually present outside of this particular experimental context, the relevance of TMS results for behaviour needs further consideration (see Perini et al., 2013), for a similar discussion in the context of neuroimaging studies of pain). In particular, it is important to consider how existing levels of motor activity might influence the effects of pain observation on the motor system, and more specifically, on overt motor action. Indeed, interactions within the motor system have been shown to be state-dependent. Using TMS and fMRI, Bestmann et al. (2008) found that the influence of the dorsal premotor cortex (PMd) on the contralateral motor cortex depended on the existing state of the motor system; stimulation over PMd led to decreased activity in the contralateral motor cortex when

participants were at rest, but increased activity when participants were performing an action. As such, it is possible that the direction of motor cortical excitability modulation during pain perception could be different when an individual is in an active (rather than a relaxed) state.

To examine the potential influence of motor state on sensorimotor resonance, we can draw on behavioural studies of pain observation. Unlike most TMS studies, these types of experiments require participants to make a motor response after observing a painful stimulus. Morrison et al. (2007b) report a Go/No-Go task in which participants saw either a sponge or the fingertips of a hand being pricked by a needle or touched by a Q-tip, prior to the presentation of a signal. The Go and No-Go signals appeared either 100ms or 500ms after video offset, and participants were instructed to respond to the Go signals by either pressing or releasing a specific key with their index finger. The researchers found that key releases were faster, and key presses slower, when the participants watched the hand getting pricked by the needle and when the Go signal appeared 500ms after the video. They posited that these results could reflect a slowing of approach (key presses) and facilitation of withdrawal (key releases) behaviours elicited by viewing the painful stimuli. The faster key release is an indicator of wanting to move away from the stimuli, whereas the slower key press is an indicator of not wanting to move towards the stimuli. The fact that the effect of pain on behavioural responses emerged only 500ms after video offset, whereas changes in corticospinal excitability can be seen immediately when a painful stimulus is observed in TMS studies, could indicate that the motor system response to observing a painful event in another individual consists of an initial suppression, followed by subsequent facilitation to support an appropriate response.

In another study by Morrison et al. (2007a), participants were shown painful and non-painful items striking a person's middle finger. The items either hit or missed the finger. In one block, participants were tasked with pressing a button (using their middle finger)

on any trial where the item successfully hit the finger. In another block, they responded only to the misses. It was found that the key presses were faster when participants responded to seeing the item successfully hit the finger, compared to when the item missed the finger. Although this effect was present across both pain and non-pain trials, responses were faster on pain compared to non-pain trials in the 'hit' condition, and were faster for trials where a painful item was shown to hit the finger compared to when it missed. Additionally, they also found significantly slower responses in the pain condition compared to non-pain when the item missed the finger.

The two sets of findings reported by Morrison and colleagues present an interesting disparity. While one study (Morrison et al., 2007b) revealed slower key presses (but faster key releases) associated with pain compared to non-pain observation, the other (Morrison et al., 2007a) indicated faster key press responses associated with pain observation. It is possible that the disparity can be explained by differences in the observed stimuli. In Morrison et al. (2007b), the painful stimuli comprised a needle pricking the fingertips of an observed hand, whereas participants in Morrison2007 observed a hand being struck from above by a pain-inducing object (e.g., a hammer). The effects of pain observation on an observer's motor excitability or behaviour are thought to be driven by a simulation of the observed individual's state. That is, the observer's motor system responds as if they themselves were receiving the painful stimulus (e.g., Avenanti et al., 2005). If this is the case, then we might expect that the mode of delivery of the observed pain would influence the observer's response to it. In Morrison et al. (2007b), participants were slower to execute responses that involved pressing down with their index finger, and faster to execute responses in which they lifted their finger upwards, when watching the painful stimulus. Since the stimulus in this case showed a needle entering the fingertips, the modulation of responses is consistent with an avoidance of the painful stimulus. The stimuli presented to participants in Morrison et al. (2007a), however, showed a painful stimulus hitting the hand from above. Thus, the speeding of key presses could

actually reflect a speeding of avoidance, since pressing downwards might be considered as an attempt to move away from the painful stimulus. Of course, this suggestion is speculative, because a downward movement may not actually be an effective avoidance response in this case. For example, a lateral movement would be more appropriate for an object hitting the hand from above.

If downward movements like key presses are not considered effective avoidance responses, there is another potential explanation for the results reported by Morrison et al. (2007b) and Morrison et al. (2007a). Specifically, there could be important differences arising from the use of an approach/avoidance response set (press versus lift) in Morrison et al. (2007b), compared to a simple key press response in their second study (Morrison et al., 2007a). In Morrison et al. (2007b), the required responses parallel adaptive action – to release and avoid, or to press and approach. This creates a situation in which release actions are quite "naturally mapped" to an observed pain stimulus delivered to the fingertip, and hence the RT advantage for releases in this condition is not surprising. In the Morrison et al. (2007a) study however, assuming that key presses cannot be conceived as effective avoidance responses, there was no approach/avoid function of the required responses. Rather, participants simply pressed a button to respond throughout the experiment. In the absence of a more adaptive response alternative, like a lateral movement (to "dodge" the painful stimulus), the key press action remains strongly mapped in this experimental context (e.g., via pre-instruction). Thus, it may make sense to equate the faster key press RTs in this experiment with the faster key release RTs in the previous experiment when comparing the two studies. If we do this, then it appears that any required action of the relevant effector is facilitated by pain observation. A recent study by Perini et al. (2013) found that experiencing pain first-hand leads to faster key presses made with the other hand, which seems to support a link between the experience of pain and motor facilitation.

Although Perini et al.'s (2014) findings suggest that experiencing pain is associated

with motor facilitation, their results introduce another question. Since the facilitation was seen in the hand that was not being stimulated, this effect cannot be construed as an avoidance response (although it may be construed as a more general response to do something with the "free" hand to reduce the pain). Furthermore, our consideration of response set differences in the two Morrison et al. studies does not shed light on the difference in response times at 0ms and 500ms after the video. On balance then, it appears that pain observation may facilitate motor action, but there is no clarity about the temporal properties or the effector/muscle specificity of this effect.

In contrast to behavioural studies, TMS studies often find a muscle specific inhibition due to pain observation (e.g. Avenanti et al., 2005; Avenanti et al., 2009a; Avenanti et al., 2009b; Avenanti et al., 2010; De Guzman et al., 2016). Furthermore, no reaction time study (that we are aware of) has examined whether these findings are effector specific. There are also discrepancies with the type of stimuli used in behavioural and neurophysiological studies. While Morrison et al. presented stimuli depicting a person's finger in a painful situation, most TMS studies of pain observation use stimuli that depict pain applied specifically to the FDI (or other muscles that are easily activated via motor cortical TMS). It is possible that the location of the observed painful stimulation differentially affects modulation in behavioural and TMS studies. Given these differences, it becomes quite difficult to compare the two types of studies to understand how the perception of painful stimuli modulates the motor system and (consequently) behaviour.

To shed further light on how the motor system is affected by pain observation, in the current behavioural study, we cued participants to press a button either immediately after observing a pain or non-pain video, or after a 500ms delay, with their finger or their foot. To better consider our results in relation to TMS studies, we used stimuli created by Avenanti et al. (2010) depicting a hand being stabbed by a needle or touched by a Q-tip (both applied to the FDI). To better consider our results in relation to previous behavioural studies, our participants completed a Go/No-Go task, in which

each imperative cue was preceded by a pain or non-pain video. To address the question of when any reaction time effects occur after video presentation, the Go/No-Go cue in our study was presented either directly after the video, or 500ms after the video. Presenting the Go signal without delay parallels some TMS studies in which a single pulse of TMS is often delivered immediately after the painful event in the video. Importantly, to assess whether any observed effects are effector specific, in different blocks, participants responded with either their right index finger, or their foot.

We can generate different predictions depending on how we weight evidence from previous experiments. First, if we grant that the general pattern of behavioural data suggests response facilitation after pain observation, we would predict response facilitation in the current study. However, there is no strong basis for a prediction about the timing of response facilitation – that is, whether it will be present for immediate actions and delayed actions. With respect to effector specificity, if the results of Perini et al. (2013) for experienced pain transfer to observed pain, we expect both finger and foot responses to be facilitated. Alternatively, if we concede that behavioural studies are inconsistent and we rely solely on previous data from TMS studies, we might predict muscle specific inhibition during pain observation (e.g. Avenanti et al., 2005), which translates to an expected slowing of responses made by the finger but not of responses made by the foot (since it is always the FDI being stimulated in the videos in our experiment). Again though, there is no clear basis on which to predict whether this effect will differ for actions cued immediately after video observation and actions cued after 500ms.

2.4 Methods

2.4.1 Participants

Twenty-four right-handed undergraduate volunteers (mean age = 19.29; male = 6) from the McMaster University psychology pool participated in this study for course credit. Prior to participation, participants provided written informed consent. The study was approved by the McMaster Research Ethics Board (MREB).

2.4.2 Apparatus & Stimuli

We used short videos developed by Avenanti et al. (2010) depicting a Caucasian hand being stabbed by a needle or lightly touched by a Q-tip on the area of skin overlying the FDI. Each video lasted for 1800ms and consisted of three different videos with the colour of the syringe or Q-tip handle varying. As per Avenanti et al. (2010), this was done to minimize effects of habituation. The two stimulus types were randomized across trials. The experiment was programmed and presented using Superlab v4.5 (Cedrus Corporation, San Pedro, CA, USA), and was run on a Dell desktop computer. Participants responded with their right index finger using a Cedrus RB series Response Pad, and with their right foot using either the space bar of a keyboard or a foot pedal. Due to technical issues, we were unable to use the foot pedal at the beginning of the study. As a substitute for the foot pedal, the first ten participants responded by pressing the spacebar of a computer keyboard with their foot. Because we used a within-subject design—wherein all comparisons between conditions were within participants—we do not perceive this use of different modalities as problematic[1]. The signals used for the

[1]To make sure that this did not influence the results, we conducted a 2x2x2 mixed-design ANOVA, with Video Type (Needle, Q-tip) and Signal Delay (0ms, 500ms) as within-subjects factors, and Apparatus (Space bar, Foot Pedal) as the between-subjects factor. Apparatus did not significantly interact with the other two factors. This suggests that the main effects reported were not influenced by the Apparatus used for foot. Interestingly, our analysis revealed a main effect of Apparatus ($F(1,22) = 11.47$, $p < 0.01$). This indicated that participants who responded using the space bar were faster than those who used the foot pedal. It is unclear why this is the case. One possibility that participants found it easier to press the space bar compared to the foot pedal, or that the space bar was more sensitive to the initial

Go/No-Go task consisted of orange and purple squares (counterbalanced between participants). Participants also completed the Interpersonal Reactivity Index (IRI) to collect self-report measures of empathy (Davis, 1983).

2.4.3 Design

The experiment used a 2x2x2 repeated-measures design, with the factors Video Type (Needle, Q-tip), Signal Delay (0ms, 500ms), and Effector (Index Finger, Foot). The experimental session was split into two blocks, with some participants responding with their Index Finger in the first block, while others started with their Foot (counterbalanced). Each block contained a total of 216 trials. These consisted of 54 trials per Video Type x Signal Delay conditions (Needle-0ms, Needle-500ms, Q-tip-0ms, Q-tip-500ms). Of those 54 trials, 42 consisted of Go trials.

2.4.4 Procedure

Participant sat in front of a computer monitor and were told that they would see visual cues in the form of coloured squares, and they should press the designated key with their finger or foot as fast as they could on the assigned Go signal, but not to the No-Go signal. Furthermore, they were told that they would be shown a video depicting a hand being stabbed by a needle or touched by a Q-tip before each signal. Following Avenanti et al. (2005), we instructed participants to "imagine what the other person is feeling" while watching the videos in order to better elicit empathic responses. On each trial, a black screen was shown for 500ms. This was followed by a video (1800ms). The Go or No-Go signal was shown either immediately at video offset, or 500ms after the end of

movement of the foot, thus making responses made by participants using this modality appear faster than responses made by participants using the foot pedal. This could also be merely due to sampling bias, with participants who responded using the space bar simply responding more quickly than those responding using the foot pedal. Regardless of the source of this effect, since Apparatus was not shown to interact with Video Type or Delay in our analysis, we can be confident that any differences between responses made with the space bar and foot pedal did not influence the main results reported in this paper.

the video. For the first block participants responded exclusively with either their right index finger or foot; they would then switch to the other for the second block (See Figure 2.1). At the end of the experiment, participants completed the IRI.

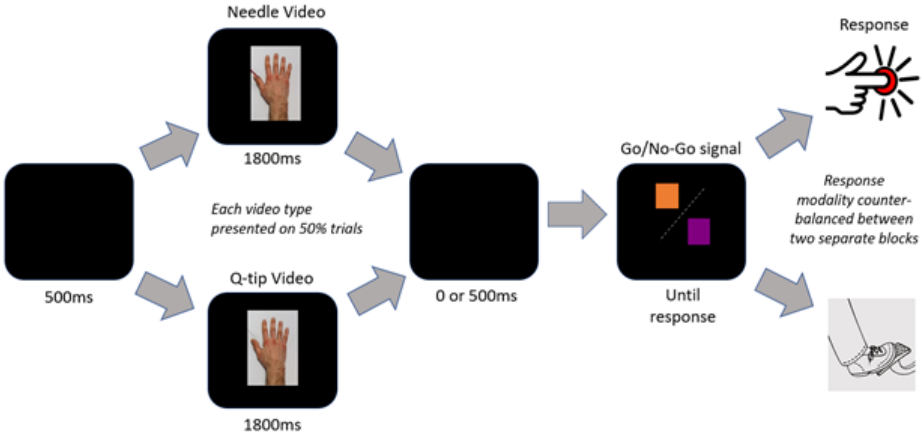

FIGURE 2.1: Schematic of experimental procedure.

2.5 Results

2.5.1 Reaction Times

Average mean error (responding to the No-Go signal) rate was 4.2%. Correct response reaction times less than 150ms or greater than 1000ms were removed (less than 1% of total trials). The remaining correct response reaction times were entered into a 2x2x2 repeated-measures ANOVA with Video Type, Signal Delay, and Effector as factors. No significant interactions were found between any of the factors. However, main effects for each factor were significant, and are depicted in Figure 2.2.

Participants were faster at responding when using their index finger ($M = 376$ms; 95% within-subjects CI [355.4ms 396.1ms]) than with their foot ($M = 465$ms; 95% within-subjects CI [444.6ms 485.3ms]) ($F(1,23) = 73.88$, $p < 0.0001$, $\eta_p^2 = 0.76$). Participants were also faster at responding when the Go signal occurred 500ms after the video ended ($M = 400$ms; 95% within-subjects CI [393.6ms 406.5ms]) compared to when it occurred

immediately after (M = 440ms; 95% within-subjects CI [434.1ms 447.1ms]) ($F(1,23)$ = 151.28, $p < 0.0001$, $\eta_p^2 = 0.87$). Finally, participants responded faster when they observed a Needle video (M = 414ms; 95% within-subjects CI [410ms 419.5ms]) compared to a Q-tip video (M = 426ms; 95% within-subjects CI [421.2ms 430.6ms]) ($F(1,23) = 21.45$, $p < 0.001$, $\eta_p^2 = 0.48$) before responding to the Go signal.

2.5.2 Interpersonal Reactivity Index

Due to technical difficulties and time constraints, only 20 of the 24 participants completed the IRI. An "Empathy Index" was calculated for each of these participants by subtracting their reaction times in the Needle from the Q-tip condition. These were then correlated with each of the IRI subscales (Fantasy Scale (FS), Empathic Concern (EC), Perspective Taking (PT), Personal Distress (PD)). No significant correlations were found (FS: $r = 0.17$, $p = 0.46$; EC: $r = 0.24$, $p = 0.3$; PT: $r = 0.12$, $p = 0.6$; PD: $r = 0.3$, $p = 0.19$).

2.6 Discussion

The effects of observing others in pain on motor activity have been explored using both neurophysiological and behavioural methods. The results of studies using TMS and EMG to assess motor activity during or immediately after pain observation suggest that observing another individual in pain leads to muscle-specific decreases in corticospinal excitability (e.g., Avenanti et al., 2005; Avenanti et al., 2009a; Avenanti et al., 2009b; Avenanti et al., 2010; De Guzman et al., 2016), which mirrors what is found when a person experiences pain themselves (e.g., Farina et al., 2001). Since an important requirement of many TMS studies is that participants remain still with their muscles relaxed, it is possible that pain observation affects the motor system differently when an individual is in a state of motor preparedness. It is possible that the state of preparing an action may lead to facilitation of a mapped response (Bestmann et al., 2008). One way to address this issue is by looking at studies of reaction times, which do not require

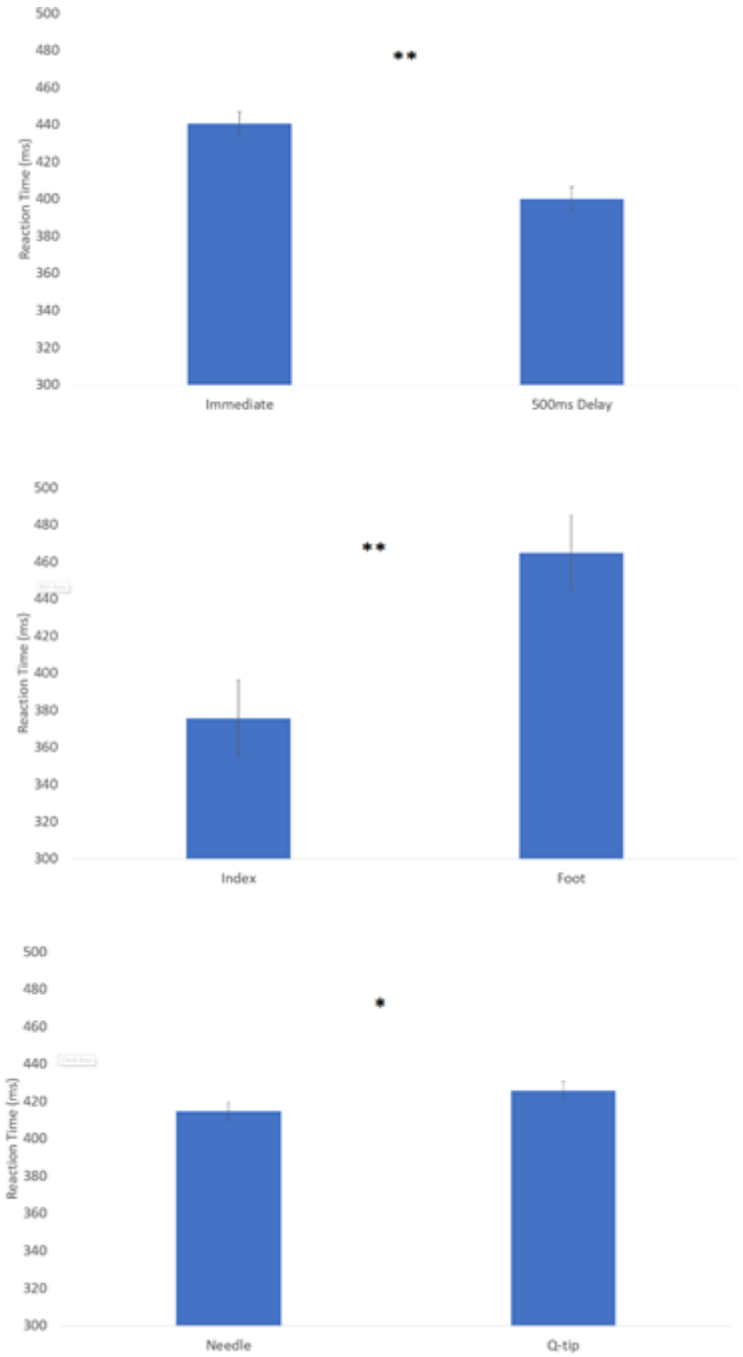

FIGURE 2.2: (a) depicts faster reaction times for responses with the index finger compared to foot. (b) depicts fasters reaction times when there was a 500ms delay of the Go signal compared to when it appeared immediately. (c) depicts faster reaction times after watching the pain stimuli compared to non-pain. * indicates $p < 0.001$; ** indicates $p < 0.0001$. Error bars represent within-subjects 95% confidence intervals (Loftus and Masson, 1994; Cousineau, 2005; Morey, 2008).

participants to remain still. Morrison et al. (2007b) found a slowing of key presses 500ms after pain observation, but a speeding of key releases at the same time. They discussed this pattern of reaction times in relation to facilitation of withdrawal and inhibition of approach related behaviour. However, in another study (Morrison et al., 2007a), key presses were speeded immediately after pain observation. As noted in the introduction, the discrepancy between these studies may be due to the response requirements; that is, in Morrison et al. (2007b) the actions were adaptive – to release and avoid, or to press and approach – whereas there was arguably no such mapping in Morrison et al. (2007a). In the absence of such a mapping, facilitation may occur regardless of the type of action required. These results contrast the muscle-specific inhibition during or immediately after pain observation often found in TMS studies. Furthermore, we noted that it is difficult to compare the two types of studies given the different types of stimuli used.

Our results show that reaction times were significantly faster when participants responded with their index finger compared to when they responded using their foot. This may be due to the fact that people are more experienced at responding with their hand compared to their foot, and that efferent conduction length for the foot is longer than that for the finger (Obhi et al., 2009). We also found that participants were faster when the Go signal was delayed by 500ms compared to when it appeared immediately. Past research has shown that, when an imperative signal is presented at various latencies following a warning stimulus, reaction times decrease as a function of the length of the preceding foreperiod – "the foreperiod effect" (Niemi and Näätänen, 1981; Woods et al., 2015). The same type of effect may explain why responses were faster 500ms after the video. Alternatively, it could be the case that the motor response to observed pain evolves from a moderate facilitation immediately after stimulation to a larger facilitation half a second later.

The most important finding of the present study is that participants responded faster to the Go signal after pain observation compared to when they had just watched a

non-painful stimulus, thus corroborating past behavioural findings. Furthermore, it did not matter whether the participant was responding with their index finger or foot. These results are in line with our predictions made in the introduction, although we did not make a strong prediction about the timing of any observed facilitation. These results are different to what might be expected based on previous TMS studies, which have demonstrated muscle-specific inhibition following pain observation. Although the present study lacks any direct measure of corticospinal excitability, the faster reaction times following pain observation suggests higher, rather than lower, motor excitability for this condition. A key feature of our design involved the use of stimuli created for TMS studies by Avenanti et al. (2010), so this apparent discrepancy cannot be explained by visual differences in the stimuli. It also did not matter whether the signal appeared immediately or 500ms after the video suggesting that this facilitation effect is temporally extended.

Since the modulation of corticospinal excitability during pain observation (Avenanti et al., 2005) seems to mirror that which occurs during the direct experience of pain (Farina et al., 2001), we might also expect the reaction time effects of observing pain to be similar to the effects of experiencing pain. In this regard, our finding of faster reaction times following pain observation is consistent with a previous study by Perini et al. (2013), who found that experiencing pain first-hand is associated with faster reaction times in the opposite hand.

An important question is why motor suppression effects occur in TMS studies, whereas we find a motor facilitation effect for the same pain stimuli in our reaction time study. One possibility is that the instructions to either remain still and relax or to prepare an action affect how the motor system responds to the observation of pain. Bestmann et al. (2008) reported a state dependency in which opposite effects of dorsal premotor cortex stimulation on excitability in the motor cortex depended on whether the participants were at rest or performing an action. It is possible that the muscle-specific decrease

during pain observation found in previous studies is at least partially due to participants actively trying to relax their muscles and the explicit intention not to move, as TMS pulses are delivered. By suggesting that the state of the motor system induced by task instructions plays a role in previously observed TMS effects, we do not mean to imply that this motor suppression effect is completely unrelated to the pain status of the stimulus. After all, the effect of being relaxed and not having an intention to move would be present during both pain and non-pain observation, and past studies have found a significant difference between these two conditions. We propose that task instructions interact with stimulus type to produce particular patterns of modulation in TMS and behavioural studies respectively. In contrast to TMS studies, in behavioural studies in which movement is instructed after the pain/no pain stimulus, the pattern of results differs, such that responses after pain stimuli are speeded compared to responses after non-pain stimuli. Furthermore, in our behavioural measure, this facilitation was not effector specific, as we found this speeding effect for both finger responses and foot responses. It is interesting to note that, in their TMS study, Avenanti et al. (2009b) found opposite effects on motor excitation depending on whether the muscle they assessed was the same as, or different to, the muscle receiving the stimulus in the video. Specifically, they found the usual muscle specific decrease when they measured activity in the same hand (congruent to the video), and an increase when they assessed the opposite hand. They couched their findings in terms of adaptive responses to pain – that is, they posited "*that the increase of corticospinal excitability may be specifically linked to the functional relation between the two hands when perceiving pain. While receiving a painful stimulus on one hand may induce a freezing reaction in that hand, the opposite hand may be more involved in actively reacting to the painful stimulus, e.g., removing the source of pain*" (pg. 1076).

We agree with this interpretation. In fact, the behavioural results reported by Perini et al. (2013) also found faster reaction times for the hand not receiving the painful

stimulus. However, given the current study's findings, it remains possible that the suppressed motor excitability in TMS studies found for the congruent hand may be influenced by an interaction between the pain status of observed stimuli and task-specific instructions.

Unlike Morrison et al. (2007b), we did not include a button release condition for our participants and thus, we cannot cast our results in relation to approach and withdrawal behaviour. That is, the characterization of releases and presses as corresponding to withdrawal and approach behaviour is irrelevant in our experimental context. Rather, we propose that any strongly mapped action is facilitated after pain observation. In experiments where release and press options are available, depending on where the pain is delivered, the release option may be more strongly mapped to a pain stimulus (e.g., by task instruction and by a more natural 'withdrawal' function) than the press response (e.g., mapped by task instruction only). In the absence of these two release/press response options though, the press response is the most strongly mapped response and is therefore facilitated by pain more than non-pain observation. To underscore, we are suggesting that pain observation facilitates any strongly mapped motor response after the observation when action is required.

A potential objection to any interpretation of the current results is that faster responding after pain observation is simply due to greater arousal in that condition. Indeed, it is true that the pain stimuli we used are known to generate higher levels of arousal than the non-pain stimuli (Avenanti et al., 2010). However, if arousal was solely responsible for the effects of pain observation on the motor system, it is difficult to explain why TMS studies show motor suppression for the more arousing condition. Thus, while we acknowledge that arousal could be a factor in our results, we suggest that it is unlikely that the effects of pain observation on the motor system are solely driven by differences in arousal.

Another potential objection is that, while our results suggest that viewing painful stimulation of the hand leads to an effector non-specific response facilitation, it could be argued that including an additional observed site of pain delivery would provide a more complete test of this idea. Indeed, a skeptic might argue that our results do not allow a general conclusion focused on non-specificity (i.e., our results might be in some way specific to observation of hands). While there is merit in such a view, we believe our current results are still a valuable addition to the literature. However, we acknowledge that in a future experiment, it will be important to include videos involving an additional effector. This would allow for a more confident conclusion regarding the apparently effector non-specific facilitation we observed in the current study.

The lack of significant correlations between the IRI subscales and the reaction times in the present study may be due to sample size used in this study. Avenanti et al. (2009a) found that the motor inhibition in TMS studies negatively correlates with a person's PD scores; however, they sampled 78 participants in their study – it is possible that a sample of 20 is not large enough to elicit significant correlations between the effect of pain observation on motor activity and the IRI subscales. It is also possible that PD scores correlate with neurophysiological but not with behavioural measures. Further studies are needed to address this issue.

In summary, the current study revealed faster response times with both the hand and foot after viewing a painful stimulus applied to an on-screen hand. We further found that this facilitation occurred regardless of whether the movement signal was delivered immediately or 500ms after the video. This non-specific facilitation effect appears to contrast with typical findings from TMS studies that show muscle specific motor suppression. Our results do however parallel recent effects on motor responses found when participants actually receive a painful stimulus themselves (Perini et al., 2013). We suggest that task instructions to remain still or to move may play an important role in determining how pain observation affects the motor system. Further studies could

employ experimental designs in which TMS and behavioural measures are taken in the same participants, and in which task instructions are systematically manipulated. Such studies would be a useful next step in advancing our understanding of the factors that influence motor system modulation in response to pain observation.

Chapter 3

Please Empathize! Instructions to empathize strengthen response facilitation after pain observation

Galang, C.M. and Obhi, S.S. (2020). Please Empathize! Instructions to empathize strengthen response facilitation after pain observation. *Cognition and Emotion, 34*(2), 316-328.

3.1 Preface

The previous chapter showed that observing others in pain leads to a general motor facilitation effect in the form of faster response times to an imperative cue. The current chapter extends this line of research by exploring how top-down and bottom-up processes influence this effect. To manipulate top-down processes, some participants were told to explicitly empathize with the person in the video stimuli, while others were simply told to pay attention to the videos. To manipulate bottom-up processes, we varied the perceived level of pain of the video stimuli by editing the videos to showcase a needle pinprick (vs. a deep stab). Across two experiments we found that pain observation led to faster response times. However, we ultimately could not test the top-down and bottom-up conditions in experiment 1 as there was a major confound in the study – namely, the videos of the

needle pinpricks were shorter in duration compared to the full stabs. Experiment 2 fixes this issue and showed that participants who were told to explicitly empathize showed stronger motor facilitation effects compared to the participants that were merely told to pay attention to the videos. The perceived level of pain, however, did not influence these results. Importantly, these results are in contrast to previous TMS research which suggests that sensorimotor resonance is influenced by the perceived level of pain rather than instructions to explicitly empathize (Avenanti et al., 2006). As such, this chapter both corroborates the results of chapter 2 and further shows the disconnect between the effects of pain observation on overt motor behaviours and sensorimotor resonance measured via TMS.

3.2 Abstract

Recent research has shown that observing others in pain leads to a general facilitation of reaction times. The current study sheds further light on the relationship between pain observation and reaction time by exploring how bottom-up processes, in the form of perceived pain intensity, and top-down processes, in the form of explicit instructions to empathize, influence response facilitation after pain observation. Participants watched videos of a hand getting pierced by a needle or touched by a Q-tip. To manipulate bottom-up information, participants saw videos depicting either deep or shallow insertion of the needle. To investigate potential top-down modulation, half the participants were explicitly requested to empathize with the person in the video, while the other half were told to simply watch and attend to the video. Results from two experiments corroborate previous results showing response facilitation after pain observation. Critically, experiment 2 provides robust evidence that explicit instructions to empathize with a person in pain strengthen response facilitation. We discuss these results considering social cognitive neuroscience and experimental psychology studies of empathy and pain observation.

3.3 Introduction

Empathy is commonly defined as the ability to both share and understand the thoughts and feelings of others. The Perception-Action Model of empathy (PAM) suggests that this ability arises as a result of the nervous system mapping the states of others onto itself (Preston and De Waal, 2002; De Waal and Preston, 2017). Empathy as a neuropsychological phenomenon has been studied extensively in cognitive and social neuroscience using a variety of tools. This is especially true in regard to empathy for pain, wherein participants are often tasked with observing or imagining another person in some painful scenario. For example, using functional magnetic resonance imaging (fMRI), past research has shown that observing or imagining another person in pain activates some of the same neural structures (e.g., Bilateral Anterior Insular Cortex and Medial/Anterior Cingulate Cortex) that are active during the first-person experience of pain (e.g., Singer et al., 2004; Jackson et al., 2005; Botvinick et al., 2005; Lamm et al., 2011), suggesting that a form of "mirroring" or "resonance" could potentially underlie empathic processing.

While not as common as fMRI or electroencephalography (EEG), the use of single pulse transcranial magnetic stimulation (TMS) has also been used to investigate empathy for pain. TMS delivered over the motor cortex elicits motor evoked potentials (MEPs) in the corresponding muscle which can be measured via electromyography (EMG). Such measures are taken as an indication of corticospinal excitability at the time of stimulation. Using this method, Avenanti et al. (2005) showed that, when watching videos of a needle piercing a person's hand, there is a muscle specific decrease in activity compared to when watching a Q-tip touch the hand. Given that a decrease in motor activity is also seen during the first-person experience of pain (e.g. Farina et al., 2001), Avenanti et al. (2005) suggested that "[...] *the effect may be due to activation of a pain resonance system that extracts basic sensory aspects of the model's painful experience (such as source or intensity of a noxious stimulus) and maps them onto the observer's motor*

system according to topographic rules" (pg. 958). This interpretation goes hand in hand with the PAM.

Interestingly, Galang et al. (2017) have recently shown that, in the context of a behavioural paradigm in which the participant makes an overt response after watching another in pain vs not in pain, participants responded faster after watching someone in pain vs. not in pain. Furthermore, Galang et al. (2017) found an effector general effect – that is, participants responded faster after pain observation regardless if they used their right index finger or foot to make their responses (the video stimuli depicted a needle stabbing the first dorsal interosseous). While these behavioural studies may seem to be in contradiction with the aforementioned TMS studies (as a freezing response seen the latter would suggest a slowing of reaction times in the former), the differences between methodologies makes the comparisons difficult: for example, it is possible that the muscle specific freezing effect occurs during pain observation but reverses during the behavioural task, and it is arguably the case that the behavioural task involves additional cognitive processes that may explain the apparent contradiction between the paradigms. More work will be needed to fully explore this topic.

Be that as it may, Galang et al. (2017) results clearly demonstrate that pain observation leads to general response facilitation. Given the links between TMS studies of motor effects and empathy (e.g., Avenanti et al., 2010), it is important to assess whether behavioural motor effects, as reported by Galang et al. (2017), might also be linked to a type of empathic process. As previously mentioned, the PAM purports that empathy arises via the nervous system mapping the observed states of others onto itself. As such, if the speeding of reaction times after pain observation is due to this mapping, then we ought to see a speeding of reaction times after the first-person experience of pain. A pertinent study Perini et al. (2013) found that painful stimulation (both hot and cold) leads to faster reaction times compared to non-painful stimulation. In their study, participants first experienced the pain (or no-pain) stimulation a few seconds before the

appearance of a task cue, after which participants were instructed to respond as quickly as possible. This task design nicely mirrors Galang et al. (2017) motor priming design, wherein participants first saw a video of another in pain before responding to an imperative cue. Unfortunately, the fact that Perini et al. (2013) had their participants respond with the non-stimulated hand makes it difficult to compare these studies. While we are aware of one study that has used the same hand for both stimulation and response (May et al., 2017), participants in this study responded to the stimulation itself rather than a subsequent imperative cue. What is needed then is a study that has participants respond with the same hand being stimulated, while limiting the effects of the stimulation itself on reaction times (as pointed out by Perini et al. (2013)). Overall then, it remains unclear whether faster reaction times after watching another in pain are the result of an empathic response in which the observed painful event is mapped onto the observers own nervous system.

To further confuse matters, behavioural studies of the effects of pain observation on reaction time have shown mixed results. For example, a study by Morrison et al. (2007b) found that observing others in pain led to slower key presses and faster key releases (see Galang et al., 2017 for an additional study on pain observation and reaction times and a comparison between the two studies). Morrison et al. (2007b) did not interpret their results in terms of an empathic response. Instead, they made a distinction between "pain empathy" and "pain recognition". They regard pain empathy as "[...] *a compassionate state which the observer experiences on behalf of the sufferer, and which may result in prosocial actions*" (pg. 415) and pain recognition as "[...] *a basic appraisal of the pain-related nature of the sufferer's situation"* (pg. 415); and while the latter might be necessary for the former, it is not sufficient (see Coll et al., 2017 for a similar distinction). They suggested that their results are more likely due to pain recognition rather than pain empathy. It is possible that the results of Galang et al. (2017) also relate primarily to pain recognition, wherein faster reaction times occur, not due to the observer "experiencing"

the observed pain for the sufferer, but rather to the mere recognition that another is suffering. In any case, regardless of whether we consider Galang et al.'s results to be an empathic response or merely a product of a basic-appraisal (i.e., pain recognition) mechanism, it is clear that reaction times are affected by watching others in pain.

To shed further light on how reaction times are affected by pain observation, the current study explores whether the speeding of reaction times is primarily driven by top-down processes, bottom-up processes, or both. Following Avenanti et al. (2005), Galang et al. (2017) explicitly requested participants to "focus on what the stimulated individual may have felt". It is possible that the speeding of reaction times was primarily due to the participant attempting to empathize with the stimulated individual in the videos. If the instructions were absent, then perhaps the speeding effect would disappear, thus suggesting that the effect is primarily driven by the top-down intention to empathize. On the other hand, it is also possible that the effect is primarily driven by the pain stimulus itself; that is, faster reaction times would occur as a result of watching another person in pain regardless of whether the participant is explicitly trying to empathize with them or not. Furthermore, if the pain stimulus looked less painful, the effects should be attenuated. This would suggest that the effect is primarily driven by bottom-up processes. Of course, there could be an interaction between task instructions and the properties of the stimuli that could modulate reaction times.

To explore this idea, we performed two experiments. Following Galang et al.'s procedures, in experiment 1, participants completed a "Go/No-Go" task where they responded to a Go signal by pressing a button with their right index finger and withheld their response if they saw a No-Go signal. Each imperative signal was preceded by a pain or no-pain video. To test the role of top-down processes on reaction times, participants were assigned to one of two groups – one with instructions to empathize and the other with no such instructions. It is important to note that instructing participants to empathize does not necessarily mean that true empathic processes are occurring in a subsequent

task (Go/No-Go task after pain observation); while it is possible that empathy is occurring, as discussed above, it is also possible that such instructions are merely leading to increased pain recognition. Regardless, such instructions can still be used to test top-down effects on response facilitation after pain observation. To explore the role of bottom-up processes on reaction times, the videos were split into two categories – one where the needle is shown to deeply pierce the hand (i.e., a high level of perceived pain) and the other where the piercing is shallow (i.e., a low level of perceived pain). To better compare our results to those reported in Galang et al. (2017), we also varied the timing of the imperative signal so that it appeared immediately after, or 500ms after, the video ended.

In experiment 2 participants followed the same general procedures outlined above. However, two important changes were made. First, in experiment 1, the video stimuli in the "shallow" condition was created by cutting off the video stimuli duration in the "deep" condition. As such, the length of the videos in each condition (shallow: 1000ms; deep: 1800ms) differed. This unfortunately meant that we could not be sure whether any result of deep vs. shallow is due to the manipulation or the video length. Therefore, the first change in experiment 2 is the use of video stimuli that are matched for length in both conditions. Second, we assumed that participants would find the video stimuli in the shallow condition to be less painful. This assumption was tested in experiment 2 by having participants complete the short form McGill Pain Questionnaire (SF-MPQ; Melzack, 1987) for each video stimuli after completing the reaction time portion of the study.

We can generate various predictions based on the design described above: first, it is possible that the effect is primarily stimulus driven. In this case we should find an interaction between Video Type (Needle vs. Q-tip) and Perceived Level of Pain (Deep Stab vs. Shallow Pinprick). We would expect that participants have faster reaction times after seeing the needle deeply stab the hand compared to the Q-tip but not when the

needle shallowly pinpricks the hand, regardless of instructions to empathize. Second, it is possible that the effects are primarily instructions driven. In this case we should observe an interaction between Video Type (Needle vs. Q-tip) and Instructions (Present vs. Absent). We would expect that participants have faster reactions times after seeing the needle deeply stab and shallowly pinprick the hand, but this effect would be attenuated when no instructions to explicitly empathize are given. Third, it is possible that there is an interaction between Video Type, Perceived Level of Pain, and Instructions. Based on the above hypotheses, it could be the case that, when Instructions to empathize are present, faster reaction times would occur as a result of watching both the deep piercing or shallow pinprick; however, when instructions are absent, the faster reaction times would only be present for the deep stab. In other words, instructions to empathize would only have an effect when the observed stimulation intensity is low. Lastly, it is possible that neither the Perceived Level of Pain and Instructions to empathize will modulate reaction times to the videos. In this case, however, we should at least observe a main effect of Video Type (i.e., faster reaction times for pain vs. no pain videos) as seen in previous research (i.e., Galang et al., 2017).

In both experiments, we also explored the relationship between motor responses after pain observation and self-reported levels of empathy via the use of the Interpersonal Reactivity Index (IRI; Davis, 1980; Davis, 1983). The IRI consists of four subscales: Perspective Taking (PT), Fantasy Scale (FS), Empathic Concern (EC), and Personal Distress (PD) – PT reflects the tendency or ability to adopt the point of view of other people, FS reflects the tendency to transpose or identify strongly with fictional characters (in movies, plays, books, etc.), EC reflects the tendency to experience feelings of warmth, compassion and concern for others undergoing negative experiences, and lastly, PD reflects the amount of discomfort and anxiety that occurs as a result of observing the negative experiences of others. Reaction times will be correlated with self-reported levels of these subscales to test if there is a relationship between these factors.

It should be noted that we hold no strong predictions about which subscales will correlate with motor responses after pain observation, as previous studies have been inconclusive; e.g., Morrison et al.'s data suggests that EC should correlate positively with reaction time effects (larger EC scores associated with faster RT for Needle compared to Q-tip videos), while Galang et al.'s data suggests that none of the subscales will correlate.

3.4 Experiment 1

3.4.1 Methods

Participants

Fifty-two right-handed undergraduate volunteers (age = 18.61 (range = 17-28); male = 10) from the McMaster psychology participant pool participated for course credit. The chosen sample size was primarily extrapolated based on previous research (Morrison et al., 2007a; De Houwer and Tibboel, 2010; Galang et al., 2017)[1]. Prior to participation, participants provided written informed consent. The study was approved by the McMaster Research Ethics Board (MREB).

Apparatus and Stimuli

We used short videos developed by Avenanti et al. (2010) depicting a Caucasian hand being stabbed by a needle or lightly touched by a Q-tip on the area of skin overlaying the first dorsal interosseous (FDI). Each Video Type (Needle vs. Q-tip) consisted of three separate videos with the colour of the syringe or Q-tip handle varying. As per Avenanti et al. (2010), this was done to minimize effects of habituation. To show videos where

[1] A simulation-based sensitivity analysis was also conducted which found that the smallest effect size that a 2x2x2 mixed design ANOVA (1 between-subjects factor and 2 within-subjects factors) three-way interaction effect (with n = 52) could find at 80% power is partial-eta = 0.14. The sensitivity analysis was conducted using: https://github.com/Lakens/ANOVA_power_simulation. G*Power, the most commonly used power analysis tool, was not used as it cannot handle the current design. We did not include Delay as a factor in the sensitivity analysis as it was not a factor of interest for this experiment (and was added specifically to better match Galang et al. (2017) original design, rather than because we thought it would influence the results).

the needle is shallowly pinpricking the hand, the videos were cut short to a 1000ms from 1800ms. This was done for both the needle and Q-tip Video Types (as the original Q-tip videos showcase the Q-tip pushing into the FDI, the "shallow" version shows a lighter touch/push). The experiment was programmed and presented using SuperLab v4.5 (Cedrus Corporation, San Pedro, CA, USA) and was run on a Lenovo P910 ThinkStation. Participants responded with their right index finger using a Cedrus RB series Response Pad. The signals used for the Go/No-Go task consisted of orange and purple squares (counterbalanced between participants). It should be noted that we noticed that a slight error was made in the counterbalancing of orange and purple squares in experiment 1 (28 participants responded to the orange square and 24 to the purple; all other factors were fully counterbalanced). Experiment 2 fixes this problem (see below for details). Participants also completed the Interpersonal Reactivity Index (IRI; Davis, 1980; Davis, 1983) at the end of the experiment.

Design

The experiment used a 2x2x2x2 mixed factorial design, wherein Video Type (Needle vs. Q-tip), Delay (Immediate, 500ms), and Perceived Level of Pain (Deep Stab vs. Shallow Pinprick) were the within-subjects factors and Instructions (Present vs. Absent) was the between-subjects factor. Each Instructions condition was randomly assigned an equal number of participants (n = 26). To avoid having the participant anticipate whether the needle videos would portray a deep stab or shallow pinprick (which could be an extraneous task demand that could influence reaction times) we split up the experimental session into two blocks. One block consisted of videos exclusively depicting deep piercing (and the equivalent Q-tip video). The other block consisted of videos exclusively depicting shallow pinpricks (and the equivalent Q-tip video). The blocks were counterbalanced across participants. The Video Type (Needle vs. Q-tip) was fully randomized within each block. Each block contained 120 trials (30 per Time Delay x

Video Type). Of those 120 trials, 96 (80%) consisted of Go trials.

Procedure

Participants sat in front of a computer monitor and were told that they would see visual cues in the form of coloured squares and that they should press the designated key with their right index finger as fast as they could on the assigned Go signal, but not on the assigned No-Go signal. Furthermore, they were told that they would be shown a video depicting a hand being stabbed by a needle or touched by a Q-tip before each signal. Half the participants were told to 'Watch and pay attention to the videos. Imagine what the stimulated individual may have felt', while the other half were told to simply, 'Watch and pay attention to the videos'. These Instructions were partially derived from those used in Avenanti et al. (2006). On each trial a black screen was shown for 500ms. This was followed by a needle or Q-tip video clip (1800ms in the Deep Stab block, 1000ms in the Shallow Pinprick block). The Go or No-Go signal was shown either immediately at video offset or 500ms after the end of the video. The first and second block consisted exclusively of video clips in the Deep Stab or Shallow Pinprick conditions counterbalanced between subjects (see Figure 3.1). Self-paced breaks were given every 60 trials. At the end of the experiment subjects completed the IRI.

3.4.2 Results

Reaction Times

Average mean error (responding to the No-Go signal) rate was 8.3%. Correct reaction times less than 150ms (anticipations) or greater than 1000ms (missed trials) were removed before final analysis (less than 1% of total trials). The remaining correct reaction times were entered into a 2x2x2x2 mixed-design ANOVA with Video Type (Needle vs. Q-tip), Delay (Immediate, 500), and Perceived Level of Pain (Deep Stab vs. Shallow Pinprick) as the within-subjects factors and Instructions (Present vs. Absent) as

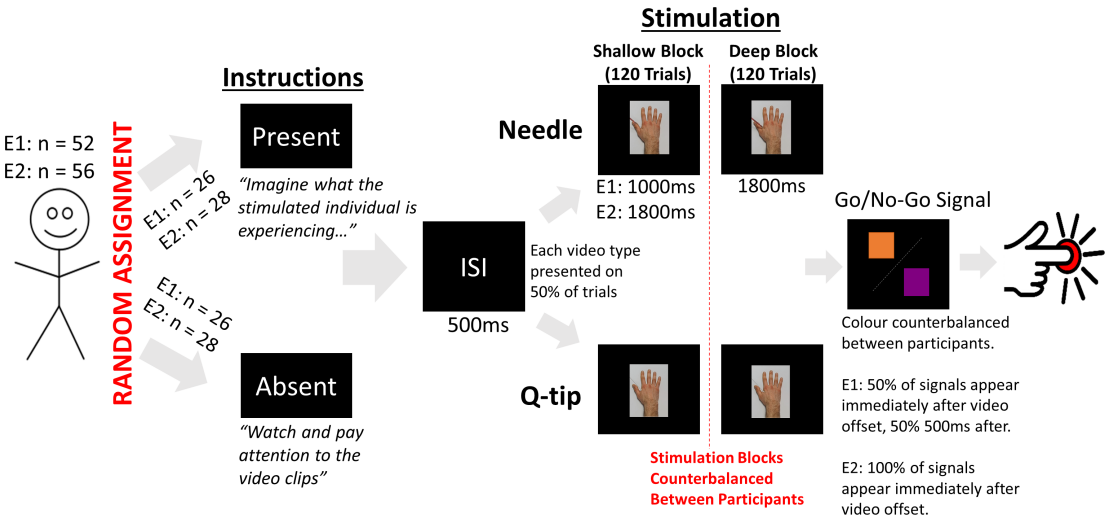

FIGURE 3.1: Experimental procedures for experiments 1 (E1) and 2 (E2).

the between-subjects factor. It should also be noted that between-subjects and within-subjects 95% confidence intervals have been calculated depending on the variables of interest (Loftus and Masson, 1994; Cousineau, 2005; Morey, 2008). To avoid confusion, between-subjects confidence intervals will be signified by "CIb" while within-subjects confidence intervals by "CIw". Following Lakens (2013), we also report 90% confidence intervals for effect sizes using F-tests (partial-eta) and 95% confidence intervals for effect sizes using t-tests (Cohen's d). Lastly, all follow-up t-tests are corrected via the Holms-Bonferroni method.

Results indicate significant main effects for each factor. A main effect of Video Type [$F(1,50) = 5.4$, $p = 0.024$, $\eta_p^2 = 0.098$, 90% CI (0.007, 0.24)] indicates that faster reaction times were obtained after watching the Needle videos [$M = 377.29$, 95% CIw (375.44, 379.15)] compared to the Q-tip videos [$M = 381.55$, 95% CIw (379.7, 383.41)]. A main effect of Perceived Level of Pain [$F(1,50) = 15.03$, $p < 0.001$, $\eta_p^2 = 0.231$, 90% CI (0.08, 0.38)] indicates that participants had faster reaction times in the Shallow Pinprick block [$M = 374.39$, 95% CIw (371.79, 376.99)] compared to the Deep Stab block [$M = 384.46$, 95% CIw (381.86, 387.1)]. A main effect of delay [$F(1,50) = 289.9$, $p < 0.001$, $\eta_p^2 =$

0.853, 90% CI (0.78, 0.89)] indicates that participants were faster at responding after a 500ms delay [M = 406.05, 95% CIw (401.03, 411.07)] compared to no delay [M = 352.8, 95% CIw = (347.78, 457.82)]. A main effect of Instructions [F(1,50) = 4.79, p = 0.033, η_p^2 = 0.087, 90% CI (0.004, 0.22)] indicates that participants in the Instructions Present group responded slower [M = 391.67, 95% CIb (373.13, 410.21)] compared to those in the Instructions Absent group [M = 367.19, 95% CIb (354.26, 380.11)]. Results also indicated a two-way interaction between Delay and Instructions [F(1,50) = 8.75, p = 0.005, η_p^2 = 0.149, 90% CI (0.03, 0.29)]. This interaction indicates that the two groups (Instructions Absent vs. Present) only differed when there was no delay, such that those instructed to explicitly empathize were significantly slower overall [M = 422.92, CIb = (401.1, 444.75)] compared to those who were told to simply watch and pay attention to the videos [M = 389.18, CIb = (375.29, 403.07] [t(50) = 2.63, p = 0.011, d = 0.73, 95% CI (0.165, 1.29)]; the difference between Instructions Present [M = 360.42, 95% CIb = (344.24, 376.59)] and Absent [M = 344.5, 95% CIb (332.12, 358.26)] in the 500ms delay condition was not significant [t(50) = 1.48, p = .146]. Crucially, results also show a three-way interaction between Video Type, Perceived Level of Pain, and Instructions [F(1,50) = 4.77, p = 0.034, η_p^2 = 0.087, 90% CI (0.004, 0.22)].

To make sense of this three-way interaction, the data was first collapsed across delay. Afterwards, the data was split up by Perceived Level of Pain and analyzed separately. That is, two separate 2x2 mixed-design ANOVAs, wherein Video Type (Needle vs. Q-tip) is the within-subjects factor and Instructions (Present vs. Absent) is the between-subjects factor, were conducted between stimulation conditions. Results indicate that only a main effect of Video Type reached significance when analyzing data solely from the Deep Peirce block [F(1,50) = 4.59, p = 0.037, η_p^2 = 0.084, 90% CI (0.003, 0.22)], wherein faster reaction times were obtained after watching the Needle videos [M = 381.87, 95% CIw (379.45, 384.29)] compared to the Q-tip videos [M = 387.05, 95% CIw (384.63, 389.47)] – See Figure 3.2a. However, a significant two-way interaction between Video

Type and Instructions was seen when analyzing data solely from the Shallow Pinprick block [$F(1,50) = 5.17$, $p = 0.027$, $\eta_p^2 = .094$, 90% CI (0.006, 0.023)]. Follow-up t-tests indicate that the expected effect was primarily driven (although not significant after correction) by the Instructions Present condition [$t(25) = 2.29$, $p = 0.062$, d = 0.45, 95% CI (0.041, 0.85)] wherein faster reaction times were obtained after watching the Needle videos [$M = 382.08$, 95% CIw (378.39, 385.77)] compared to the Q-tip videos [$M = 390.28$, 95% CIw (386.59, 393.96)]; no significant difference was found between Needle [$M = 363.36$, 95% CIw (360.95, 365.76)] and Q-tip [$M = 361.85$, 95% CIw (359.44, 364.25)] in the Instructions Absent condition [$t(25) = 0.65$, $p = .5$]. See Figure 3.2b.

Interpersonal Reactivity Index

To properly correlate these subscales with reaction times, a difference score between the Needle and Q-tip condition was created with larger scores indicating faster reaction times in the Needle condition. Given that we obtained a three-way interaction, we sought to correlate each of the IRI components (Perspective Taking (PT), Fantasy Scale (FS), Empathic Concern (EC), and Personal Distress (PD)) with the four conditions that make up the interaction: Present-Deep, Present-Shallow, Absent-Deep, Absent-Shallow. All correlations were non-significant after correcting for multiple correlations (all $p > 0.35$).

3.4.3 Discussion

The results of experiment 1 suggests that top-down information, in the form of explicit Instructions to empathize, and bottom-up processing, in the form of the Perceived Level of Pain, jointly modulates response facilitation after pain observation. Participants instructed to explicitly empathize with the person in the video showed faster reaction times during pain observation regardless of the Perceived Level of Pain; in contrast, participants not given explicit Instructions to empathize did not show any effects of

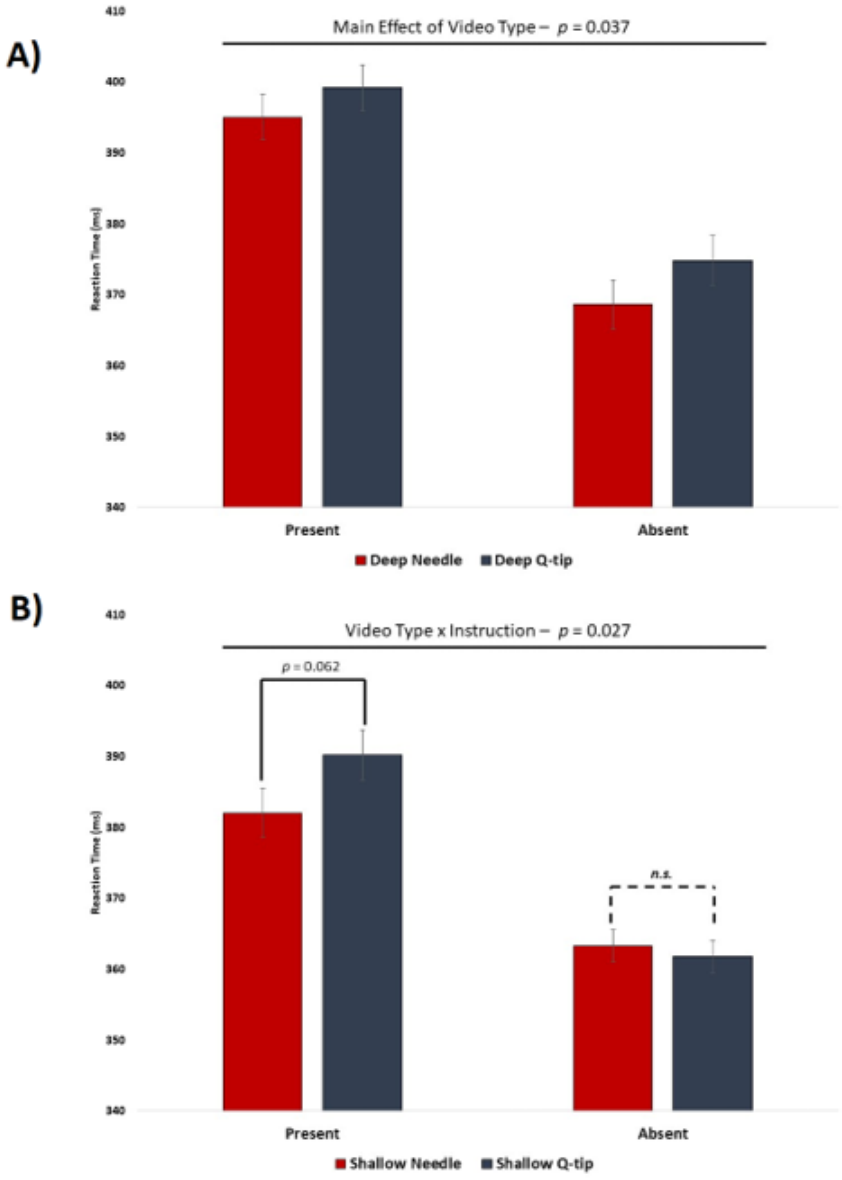

FIGURE 3.2: Significant three-way interaction between Video Type, Stimulation, and Instructions, broken down across Stimulation. A) shows a main effect of Video Type for the Deep Pierce block, showing faster reaction times for Needle compared to Q-tip in both instruction conditions. B) shows a significant two-way interaction between Video Type and Instructions for the Shallow Pinprick block. Follow-up t-tests between Needle and Q-tip conditions were conducted (Holms-Bonferroni Corrected). Error bars represent within-subjects 95% confidence intervals.

facilitation whatsoever, as the effect when the Perceived Level of Pain was high (i.e., deep stab) did not reach significant after correction (which may have been due to being underpowered if the effect size was smaller than what the current study is sensitive enough to detect at 80% power; see sensitivity analysis). While we find these results interesting, there are a few notable issues with experiment 1 that necessitate a follow up study.

Experiment 1 provides the basis to investigate the effects of pain observation on reaction time further. However, a critical limitation in experiment 1 was the use of video stimuli that were not matched for duration. That is, the videos showing the needle piercing the hand deeply were longer (1800ms) than the videos showing the more superficial piercing (1000ms). Given this shortcoming, it is possible that the apparent three-way interaction between Video Type, Perceived Level of Pain, and Instruction was affected by video length. In experiment 2, we resolved this issue by making the video stimuli in both deep and shallow piercing conditions equal in length (1800ms; videos were edited using Adobe Premiere Pro). In experiment 1, we also assumed that the videos differed in the degree of pain that they portrayed. To verify this assumption, in experiment 2 we asked participants to complete the SF-MPQ for each video stimulus (Melzack, 1987). SF-MPQ scores allow us to directly assess the Perceived Level of Pain between the deep and shallow needle conditions.

Two other minor changes were also made in an effort to perfect our experimental design. First, given the lack of interaction with delay (in both experiment 1 and Galang et al. (2017)), we opted to remove this condition in experiment 2 by limiting presentation of the imperative cue to immediately after the video offset. Second, we increased our sample size from fifty-two to fifty-six. After experiment 1, we became aware of a mistake in our counterbalancing procedure. Specifically, the counterbalancing of the orange and purple square as the Go signal was imperfect; thus, 28 participants responded to the orange square and 24 participants responded to the purple square. By increasing the

sample size in experiment 2 we were able to perfectly counterbalance the colour cues in the context of our go-no-go paradigm.

3.5 Experiment 2

3.5.1 Methods

Participants

Fifty-six right-handed undergraduate volunteers (age = 20.1 (range = 17-40); male = 9) from the McMaster psychology participant pool participated for course credit. Prior to participation, participants provided written informed consent[2]. The study was approved by the McMaster Research Ethics Board (MREB).

Apparatus and Stimuli

The crucial difference between experiment 1 and 2 is the use of video stimuli of matched duration for the Deep Stab and Shallow Pinprick conditions. These videos were created by modifying the original Avenanti et al. (2010) videos via Adobe Premiere Pro.

Design

The experiment used a 2x2x2 mixed factorial design, wherein Video Type (Needle vs. Q-tip) and Perceived Level of Pain (Deep Stab vs. Shallow Pinprick) were the within-subjects factors and Instructions (Present vs. Absent) was the between-subjects factor. Experiment 2 otherwise comprised the same design as experiment 1.

Procedure

Experiment 2 followed the same procedures outlined in experiment 1. In addition, participants completed the SF-MPQ for each video type at the end of the experiment.

[2]Increasing the sample size by 4 participants does not significantly change the original sensitivity analysis conducted for the first experiment.

3.5.2 Results

Reaction Times

Average mean error (responding to the No-Go signal) rate was 8.2%. Correct reaction times less than 150ms (anticipations) or greater than 1000ms (missed trials) were removed before final analysis (less than 1% of total trials). The remaining correct reaction times were entered into a 2x2x2 mixed-design ANOVA with Video Type (Needle vs. Q-tip) and Perceived Level of Pain (Deep Stab vs. Shallow Pinprick) as the within-subjects factors and Instructions (Present vs. Absent) as the between-subjects factor. We again report within-subjects confidence intervals where appropriate, along with confidence intervals around effect sizes. Follow-up t-tests were corrected via the Holms-Bonferroni method.

Results indicate a significant main effect of Video Type [$F(1,54) = 76$, $p < 0.001$, $\eta_p^2 = 0.585$, 90% CI (0.43, 0.68)] wherein participants responded faster after observing the Needle video [$M = 398.3$, 95% CIw (396.1, 400.5)] compared to the Q-tip video [$M = 416.7$, 95% CIw (414.5, 418.9)]. Results also indicate a significant interaction between Video Type and Instructions [$F(1,54) = 7.75$, $p = 0.007$, $\eta_p^2 = 0.126$, 90% CI (0.02, 0.26)]. This two-way interaction indicates that the difference between the Video Type conditions (Q-tip – Needle) is significantly larger in the Instruction Present condition [$M = 24.27$, CIb (17.7, 30.8)] compared to the Instructions Absent condition [$M = 12.52$, CIb (7.5, 17.6)] – see Figure 3.3. Interestingly, separate follow-up t-tests between the Needle and Q-tip conditions in each Instructions (Present, Absent) condition shows that participants responded faster after the observing the Needle videos [Present: $M = 395.4$, 95% CIw (392.1 398.6); Absent: $M = 401.2$, CIw (398.7 403.8)] compared to the Q-tip videos [Present: $M = 418.6$, CIw (416.4, 422.9); Absent: $M = 413.8$, CIw (411.2 416.3)] in both Instruction conditions [Absent: $t(27) = 4.84$, $p < 0.001$, $d = 0.92$, 95% CIw (0.47, 1.35); Present: $t(27) = 7.3$, $p < 0.001$, $d = 1.38$, 95% CIw (0.85, 1.9)] –

see Figure 3.4. In contrast to experiment 1, no other effects reached significance in the overall ANOVA (Main Effect of Level of Pain: $p = 0.14$; Main effect of Instructions: $p = 0.4$; Level of Pain * Instructions Interaction: $p = 0.18$; Video Type * Level of Pain * Instructions Interaction: $p = 0.31$).

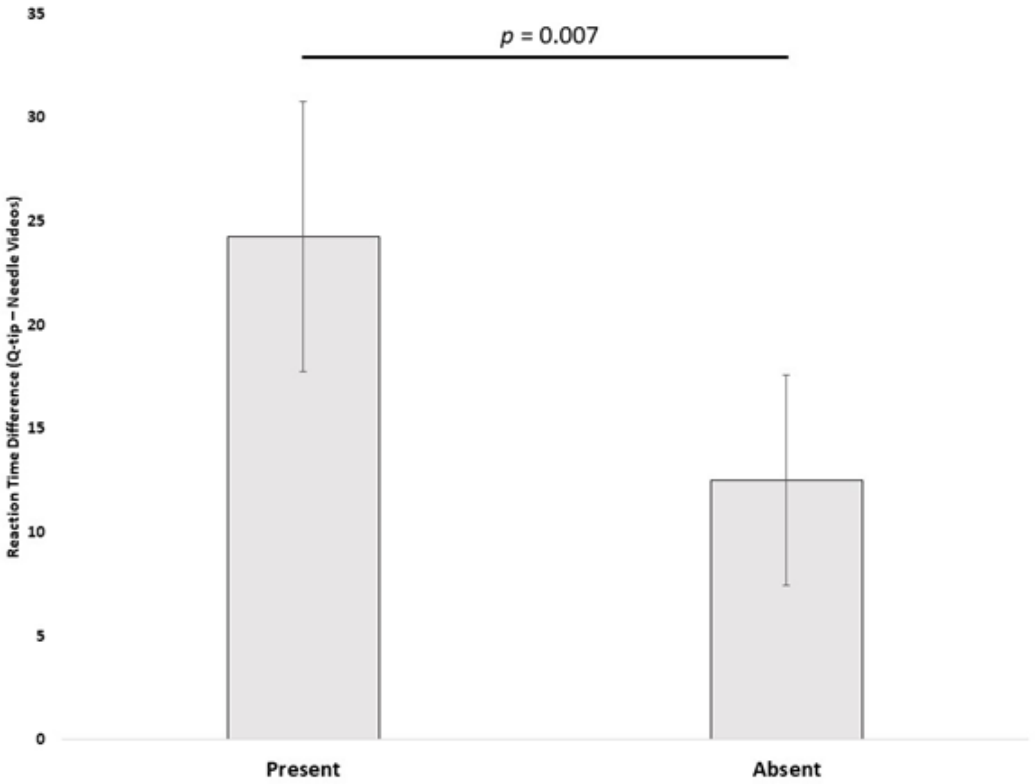

FIGURE 3.3: Significant difference between the RT difference of Q-tip and Needle conditions. This difference is equivalent to the 2x2 interaction between Video Type and Instruction conditions. More positive values indicate faster RT for Needle compared to Q-tip conditions. Not shown: both Present and Absent conditions are significantly different from 0. Error bars represent between-subjects 95% confidence intervals.

SF-MPQ

The SF-MPQ consists of two dimensions: Sensory (perceived level of pain) and Affective perceived level of emotional distress). We first compared the Needle videos to the Q-tip videos. Participants indeed rated Needle videos as significantly more painful/distressing

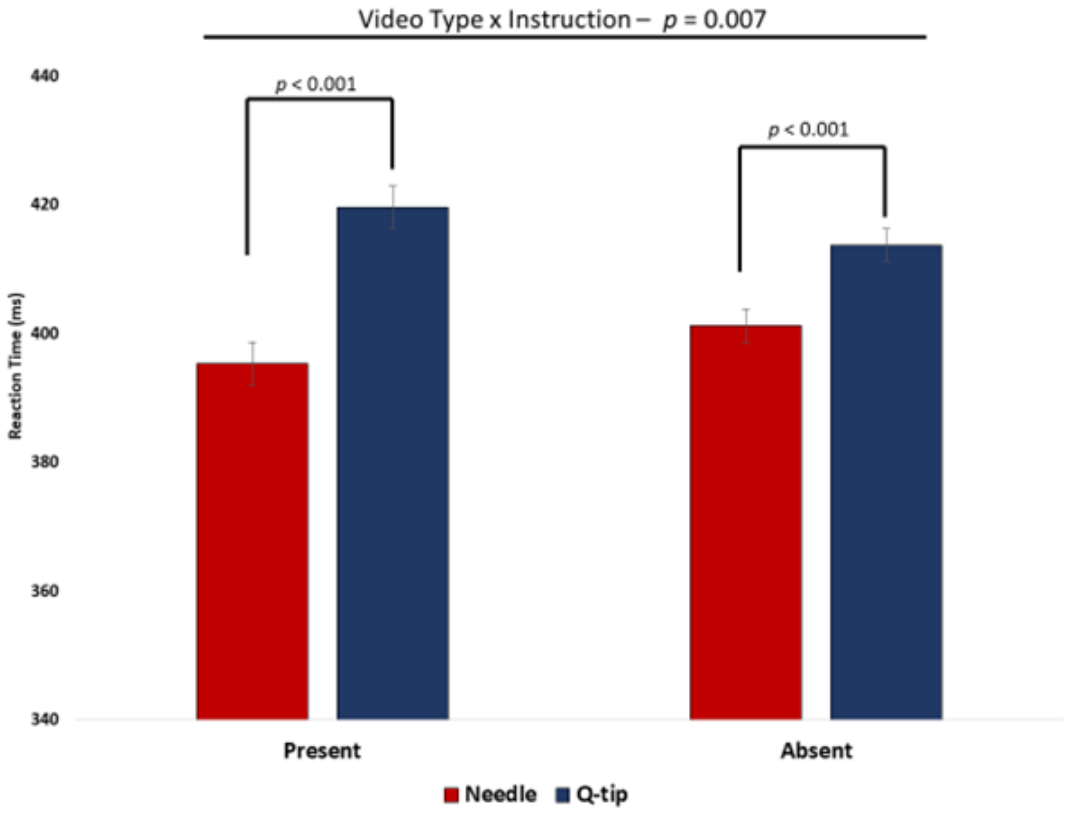

FIGURE 3.4: Significant difference between Needle and Q-tip conditions in both Present and Absent Instruction conditions. Qualified by a two-way interaction between Video Type and Instruction (See Figure 3). Error bars represent within-subjects 95% confidence intervals.

than Q-tip videos [Sensory: $t(55) = 11.5$, $p < 0.001$, $d = 1.5$, 95% CIw (1.14, 1.9); Affective: $t(55) = 8.9$, $p < 0.001$, $d = 1.2$, 95% CIw (0.85, 1.54)]. We then performed key contrasts between the Needle videos showcasing a deep stab vs. shallow pinprick, as well as the Q-tip videos showcasing a push into the hand vs. a light touch. Results indicate that, consistent with our assumption in experiment 1, the deep stab was rated as more painful and distressing compared to the shallow pinprick [Sensory: $t(55) = 10.4$, $p < 0.001$, $d = 1.4$, 95% CIw (1.02, 1.76); Affective: $t(55) = 7.1$, $p < 0.001$, $d = 0.95$, 95% CIw (0.63, 1.26)]. Results also indicate that the Q-tip push into the hand was rated as more painful compared to the light touch [$t(55) = 6.8$, $p < 0.001$, $d = 0.9$, 95% CIw (0.6, 1.2)], however, no such differences in the affective domain reached significance [$p >$

0.27]. Finally, to check if participants in the Instructions Present vs. Absent conditions rated videos differently, we performed 2x2x2 mixed-design ANOVAs for both Sensory and Affective ratings. No significant effects involving Instructions was found [all $p > 0.09$].

IRI

Given the two-way interaction between Video Type and Perceived Level of Pain found in experiment 2, we opted to correlate each IRI subscale with the difference between the Needle and Q-tip conditions collapsed across Perceived Level of Pain. No significant correlations were found [all $p > 0.35$].

3.5.3 Discussion

The results of experiment 2 suggests that the original result reported in experiment 1 was confounded by the differing lengths of videos used in the deep and shallow blocks. Indeed, rather than a three-way interaction, the results of experiment 2 indicate a robust two-way interaction between Video Type and Instructions. This interaction suggests that response facilitation (faster reaction times after Needle videos compared to Q-tip) as a result of pain observation is strengthened when participants are explicitly instructed to empathize. Note that the follow up t-tests indicated that response facilitation occurred regardless of Instructions condition. This suggests that the effects of pain observation on reaction times is robust (also indicated by the significant main effect of Video Type), however, it is also the case that explicit instructions to empathize increases the size of the effect. It is important to note that a lack of significant interaction effect with the Perceived Level of Pain does not necessarily mean that no effect exists at all (as a null result ($p > 0.05$) cannot be interpreted as favouring the null hypothesis, but rather failing to reject the null). Thus, we remain agnostic about the role of bottom-up processes and emphasize that further work is needed to more fully understand their impact.

We also found that participants did indeed find the Needle videos in the Deep Stab condition to be more painful and distressing than the Needle videos in the Shallow Pinprick condition. We also found that participants rated the Q-tip videos showcasing a push into the hand as more painful relative to a light touch. The finding that participants in the Instructions Present vs. Absent conditions did not differ in their ratings of perceived pain suggests that the current results cannot be attributed to individual differences regarding pain sensitivity (e.g., participants in the Instructions Present condition may have just been more sensitive to pain compared to those in Absent). Lastly, we again found no significant correlations with the IRI subscales and reaction times. This corroborates both experiment 1 and previous results reported by Galang et al. (2017) (we discuss this in more detail in the General Discussion).

3.6 General Discussion

Compared to the use of neurophysiological measures during pain observation, the influence of pain observation on subsequent movement is seldom studied. The current results make headway on this topic by elucidating the influence of bottom-up and top-down processes on response facilitation after pain observation. In experiment 1, our results suggested that both bottom-up and top-down processes interact to influence response facilitation. Specifically, we found that participants in the Instructions Present condition responded faster after watching the Needle videos (compared to the Q-tip videos) regardless of the Perceived Level of Pain. In contrast, participants in the Instructions Absent condition did not show this effect at all (the effect was non-significant after correction). Due to methodological limitations (i.e., differing video lengths) and weak statistical results (i.e., lack of significant effect after correction as discussed above), we opted to conduct a second experiment.

In contrast to experiment 1, experiment 2 suggests that it is top-down processes that

influence response facilitation after pain observation, at least in our paradigm. Specifically, while participants responded faster after watching the Needle videos (compared to the Q-tip videos) regardless of whether they witnessed a deep stab or a shallow pinprick, this effect was significantly larger for participants in the Instructions Present condition. This indicates that the results of experiment 1 were more than likely (or at least partially) due to the confound of video length. However, the data (specifically the main effect of Video Type) is still useful in corroborating Galang et al.'s original result that pain observation leads to faster reaction times.

One may argue that, with the current results, it is unclear whether participants in the Instructions Present condition showed stronger response facilitation due to explicit instructions to empathize or due to the increased attention to the stimuli that such instructions may lead to; indeed, it is unclear whether one can have the former without the latter. We consider two possible interpretations regarding attention: first, in a methodologically similar but conceptually distinct study, De Houwer and Tibboel (2010) found that participants responded slower to a Go signal after observing a highly arousing image (both negatively and positively valanced). This comparison between De Houwer and Tibboel (2010) and Galang et al. (2017) is apt, as both studies used similar paradigms: in both cases, participants completed a Go/No-Go task wherein participants were instructed to press a button as fast as possible if they saw one signal (e.g., an orange square) and to withhold their response if they saw another (e.g., a purple square); however, whereas Galang et al. (2017) showed videos of either a needle stabbing a hand or a Q-tip touching a hand before each imperative cue, De Houwer and Tibboel (2010) instead showed pictures from the International Affective Picture System (IAPS) (also see Verbruggen and De Houwer, 2007). They provide an attentional account of these results, pointing out that emotional stimuli command more attentional resources, and as such, detract from attentional processing of a subsequent cue (e.g., a Go signal). As such, if our results were due to increased attention due to instructions to explicitly

empathize, then we ought to have found weaker effects for the participants in the Instructions Present condition. As such, in this interpretation, attention is unlikely to have played a confounding role. However, a second possible alternative explanation is that instructing participants to empathize made the pain stimuli more motivationally relevant and the differences between pain intensity more salient. As such, in this interpretation, increased attention (in so far as it leads to increased motivational relevance and pain intensity salience) may be a possible mechanism explaining the reported effects. Indeed, given the methodological differences between Galang et al. (2017) and De Houwer and Tibboel (2010), there is no reason to favour the former hypothesis over the latter. More work will be needed to fully elucidate the relationship between attention and explicit attempts to empathize.

It is important to note that we are theory-neutral regarding the influence of instructions to empathize on response facilitation after pain observation. As mentioned in the introduction, it is possible that instructing participants to "imagine what the stimulated may have felt" led to true empathic processing which caused the strengthening of response facilitation after pain observation. However, it is also possible that such instructions merely accentuated basic-appraisal mechanisms of recognizing another's pain, which then led to the strengthening of response facilitation after pain observation. Indeed, we have been careful throughout the manuscript in interpreting our effects as due to instructions to explicitly empathize, rather than to empathy itself, to remain theory-neutral in this regard.

Lastly, we found that trait measures of empathy measured via the IRI did not correlate with the reaction time measures across both studies. This result is consistent with Galang et al.'s original results, as they also did not find any correlations. However, it is important to note that this study may have been underpowered for finding an effect for anything but large effect sizes in these correlations. G*Power (Faul et al., 2007; Faul et al., 2009) suggests that for at least a medium correlation ($r = 0.3$), we would need n =

84 for 80% power, and that our current sample sizes (n = 52; n = 56) were sensitive for detecting $r > 0.36$ at 80% power (Galang et al., 2017 used n = 24 leading to even weaker sensitivity for detecting small effect sizes at 80% power). It is possible that larger sample sizes may be needed to see a significant relationship between response facilitation after pain observation and the IRI subscales. Furthermore, it is possible that other measures of trait-empathy may be more appropriate; for example, Moreton et al. (2017) found correlations with their behavioural results and the Balanced Emotional Empathy Score questionnaire (BEES; Mehrabian and Epstein, 1972). More work will be needed to fully elucidate the relationship between response facilitation after pain observation and trait measures of empathy.

In conclusion, the current study sheds further light on the influence of pain observation on subsequent movement. Specifically, we investigated the potential modulating role of bottom-up (Perceived Level of Pain) and top-down (Instructions to Empathize or Lack thereof) processes on response facilitation. Both experiments corroborate previous results that observing others in pain (vs no pain) leads to faster reaction times, and experiment 2 indicates the role that top-down processes play in such response facilitation. Specifically, experiment 2 indicates that when participants are instructed to explicitly empathize with a person in pain, the response facilitation effect increases in strength. While more research is needed to fully elucidate the exact mechanisms underlying these findings, the current study contributes novel information about the relation between pain observation, top-down/bottom-up processes, and motor responses.

Chapter 4

Response-general effects of pain observation on motor behaviour

Galang, C.M., Pichtikova, M., Sanders, T., and Obhi, S.S. (In Prep.). Response-general effects of pain observation on motor behaviour.

4.1 Preface

The previous two chapters have shown that pain observation robustly leads to motor facilitation. However, as the response was a key press, these results run contrary to those reported in Morrison et al. (2007b) which reported that key presses led to slower response times. One possibility for this discrepancy is that Morrison et al. (2007b) had their participants respond with both key presses and releases, which may have allowed for adaptive (i.e., approach/withdraw) responses to occur as a result of pain observation. As such, the current chapter aims to test this hypothesis. Following Morrison et al. (2007b), experiment 1 had participants respond with key presses and releases as a proxy for approach and withdraw movements. As key presses and releases may not be the best proxy for such movements, experiment 2 had participants instead respond with a joystick (forward/backward movements). Across both experiments, we found no evidence for adaptive motor behaviours after pain observation. Instead, we corroborated our earlier findings and found that pain observation led to motor facilitation (regardless

of movement type). Furthermore, as the experiments in this chapter used the largest sample size to date on this topic, the results of this chapter show the robustness of this motor facilitation effect.

4.2 Abstract

Previous research has shown that motor facilitation (in the form of faster reaction times) occurs after pain observation. The current study extends this line of research by exploring if the type of action modulates this facilitation effect. Specifically, the current study tests if approach-like and withdraw-like movements are deferentially influenced by pain observation. In experiment 1, participants performed key presses (approach) and releases (withdraw) after observing another person in pain (vs. no pain). In experiment 2, participants used a joystick to make forward (approach) and backward (withdraw) movements after observing another person in pain (vs. no pain). Across both experiments, we did not find evidence for differential effects of pain observation on approach-like and withdraw-like movements; instead, we report robust support for a response-general effect of pain observation on motor behaviour. We discuss these results in relation to the wider emotion & attention and social neuroscience of empathy literature.

4.3 Introduction

When observing another in pain, our own nervous system seems to activate similar regions present when we ourselves are in pain (e.g., Singer et al., 2004; Avenanti et al., 2005; Singer and Lamm, 2009; Lamm et al., 2011; Riečanský and Lamm, 2019). This "shared network" hypothesis (Singer and Lamm, 2009) suggests that such a mapping of states may form the building blocks of empathy (also see the Perception-Action Model of Empathy; Preston and De Waal, 2002; De Waal and Preston, 2017). Some evidence for the shared network hypothesis comes from work using fMRI (functional magnetic

resonance imaging), which has shown that observing or imagining another person in pain activates the same cortical regions (e.g., Bilateral Anterior Insular Cortex and Medial/Anterior Cingulate Cortex) that are active during the first-person experience of pain (e.g., Singer et al., 2004; Botvinick et al., 2005; Jackson et al., 2005; Lamm et al., 2011). Further evidence for the shared network hypothesis comes from work using TMS (transcranial magnetic stimulation), which has shown that observing "flesh and bone" stimuli of another person in pain (e.g., a needle stabbing a hand) leads to similar cortico-spinal activity present during the first-person experience of pain (e.g., Avenanti et al., 2005; Avenanti et al., 2010; De Coster et al., 2014; De Guzman et al., 2016).

While such neurophysiological measures shed light on the mechanisms that might underlie empathy during pain observation, they do not tell us anything about the behavioural consequences of such mechanisms. One line of research that has investigated this question has explored how basic motor responses, usually in the form of a key press, are influenced by pain observation (also see Christov-Moore and Iacoboni, 2016; Christov-Moore et al., 2017). An early study by Morrison et al. (2007b) found that pain observation (i.e., a needle stabbing finger tips) leads to faster key releases and slower key presses – exclusively when the imperative cue (e.g., an orange square) to move was shown 500ms after the experimental stimuli (no effects were found when the cue was shown at 100ms). They suggested that these results could reflect an adaptive response wherein a facilitation of withdrawal (i.e., key release) and attenuation of approach (i.e., key press) responses are elicited after observing another in pain.

In another study by the same group, Morrison et al. (2007a) found that key presses were facilitated after pain observation. However, in this case participants had to respond immediately after seeing the object hit or miss a hand. Faster responses were found when noxious objects (e.g., a hammer) hit the hand vs. an innocuous object (e.g., a spoon), and vs. misses of either object type. They also report that noxious misses elicited faster response times compared to innocuous misses, suggesting that merely observing a

potentially harmful object near another person is enough to elicit faster response times from the observer.

More recent work by our group has shown that observing another person in pain leads to a general and temporally extended response facilitation effect (Galang et al., 2017; Galang and Obhi, 2020). In Galang et al. (2017), participants observed videos of a hand getting stabbed by a needle or touched by a Q-tip (the same videos used in previous TMS studies; Avenanti et al., 2010). After each video, an imperative cue (i.e., an orange square) appeared that would either indicate the participant to respond or to withhold a response (i.e., a Go/No-Go task). Importantly, these cues appeared either immediately after the video stimuli or with a 500ms delay, and participants responded either with a key press with their right index finger, or with a foot press using a pedal. The former manipulation combines the temporal parameters of the effects that were found in Morrison et al. (2007b) (500ms) and Morrison et al. (2007a) (immediately at the end of stimuli observation), while the latter manipulation can test for effector-specific effects (as TMS studies often report a muscle-specific effect of pain observation on cortico-spinal activity; e.g., Avenanti et al., 2005).

Galang et al. (2017) reported that participants responded faster to the imperative cue after pain observation (vs. no pain) regardless of the temporal property of the cue and the effector used to make a response. These results seem to contrast those reported by Morrison et al. (2007b), wherein they reported slower response times to key presses when the imperative cue was shown 500ms after pain observation; however, the results do seem to corroborate Morrison et al. (2007a) (a general facilitation of motor responses after pain observation). The effector-general effect is also in contrast to the muscle-specific effect found in TMS studies; however, we do not discuss this point further here as we do so elsewhere (Galang and Obhi, 2020; also see Riečanský and Lamm, 2019). Follow-up experiments reported in Galang and Obhi (2020) corroborated these initial findings, and further showed that instructing participants to explicitly empathize with

the model in the video (vs. no empathy instructions) led to stronger motor response effects due to pain observation.

Other recent work has largely corroborated the finding that pain observation leads to faster response times; for example, in their behavioural results, Fabi and Leuthold (2016) report that participants respond faster (via a key press), and with more force, after observing another person in a painful situation (e.g., a hammer hitting a hand; also see Fabi and Leuthold, 2018; Galang et al., 2020). Interestingly, the stimuli were pictures (in contrast to the videos or apparent motion used in the studies described thus far) and were displayed for only 200ms. This suggests that the effects of pain observation on motor behaviour may work in an implicit fashion.

Given these recent findings, the evidence seems to strongly suggest that observing another in pain leads to faster responses from the observer; however, it remains unclear why recent studies do not corroborate Morrison et al. (2007b): faster key releases but slower key presses. Of course, recent studies have primarily focused on key presses over releases, and most have participants immediately respond after the experimental stimuli is presented. However, Galang et al. (2017) and Galang and Obhi (2020) (experiment 1) both had conditions that delayed the imperative cue by 500ms, and yet key presses were still found to be faster after pain observation. One possibility discussed in Galang et al. (2017) is that Morrison et al. (2007b) provided participants with a natural mapping of an adaptive behaviour – approach and withdraw. In contrast, all other studies essentially force participants into one movement type. As such, it is possible that, when provided with the option of performing more adaptive behaviours, the pattern of results reported in Morrison et al. (2007b) emerges; in lieu of such a choice, it may be the case that any behavioural response will necessarily lead to facilitation after pain observation; we refer to this as the Natural-Mappings hypothesis throughout the paper. Note that this is an important question, as the functional significance of these response time effects have yet to be fully explored (although see Han et al., 2017). And as such, showing that adaptive

behaviours emerge as a result of pain observation (when given the opportunity) will help us shed further light on this topic.

As such, the aim of the current study is to test the Natural-Mappings hypothesis. To do so, participants completed a Go/No-Go task responding (or not) to coloured squares. Videos of a hand getting stabbed by a needle or touched by a Q-tip (the same as those used in Galang et al. (2017) and Galang and Obhi (2020)) were interleaved between each imperative cue. Furthermore, the imperative cue either appeared immediately after the video stimuli or after a 500ms delay. To better match Morrison et al.'s (2007b) original design, in experiment 1, participants alternated between key presses (approach) and releases (withdrawal). However, in experiment 2, participants used a joystick to perform more natural approach and withdraw movements.

Given this design, the Natural-Mappings hypothesis predicts that participants will perform slower key presses/joystick forward movements and faster key releases/joystick backward movements after pain observation. A strict interpretation of the Natural-Mappings hypothesis would predict that this effect should specifically be found when the imperative cue appears after a 500ms delay (matching Morrison et al.'s (2007b) original results). However, a more general interpretation predicts that such an effect will occur regardless of delay. Of course, it is also possible that the Natural-Mapping hypothesis is not confirmed in these experiments. In this case, however, we at the very least expect to replicate recent work and find faster responses after pain observation (vs. no pain), regardless of all other conditions.

4.4 Experiment 1

4.4.1 Methods

Participants

60 participants were recruited to participate in this study for course credit (male = 13; mean age = 20.4 [SD = 5.2]). Prior to participation, participants provided written informed consent. The study was approved by the McMaster Research Ethics Board (MREB).

Apparatus and Stimuli

The experiment was programmed and presented using SuperLab v4.5 (Cedrus Corporation, San Pedro, CA, U.S.A.) and was run on a Lenovo P910 ThinkStation. Participants responded to a Dell keyboard spacebar using their right index finger. We used short videos developed by Avenanti et al. (2010) depicting a Caucasian hand being stabbed by a needle or lightly touched by a Q-tip on the area of skin overlaying the first dorsal interosseous (FDI). Each Video Type (Needle vs. Q-tip) consisted of three separate videos with the colour of the syringe or Q- tip handle varying. As per Avenanti et al. (2010), this was done to minimise effects of habituation. At the end of the experiment, participants completed the Interpersonal Reactivity Index (IRI; Davis, 1980; Davis, 1983).

Design

The experiment used a 2x2x2 within-subjects ANOVA design, wherein Video Type (Needle, Q-tip), Movement Type (Press, Release), and Delay (Immediate, 500ms), were the factors of interest. The crossed Video Type x Delay factors (i.e., Needle-Immediate, Needle-500ms, Q-tip-Immediate, Q-tip-500ms) were fully randomized throughout the experiment; however, following Morrison et al.'s (2007b) procedures, participants alternated between Presses and Releases throughout the experiment (participants would

press the spacebar and hold it until the next trial where they would then release it). To avoid possible order effects, we counterbalanced which Movement Type participants started with across participants. Participants completed 8 blocks of 60 trials each. 80% of total trials were Go signals (384/480 trials). This leads to 48 Go trials per fully crossed Video Type x Movement Type x Delay factors (i.e., Needle-Press-Immediate, Needle-Press-500ms, Needle-Release-Immediate, Needle-Release-500ms, Q-tip-Press-Immediate, Q-tip-Press-500ms, Q-tip-Release-Immediate, Q-tip-Release-500ms).

Procedure

Participants first read over a letter of information going over the tasks in the study. If they were comfortable with the procedures, they were asked to sign a consent form. For the main experimental task, participants were told that they would see visual cues in the form of coloured squares. One colour (e.g., orange) would represent the Go signal, while another colour (e.g., purple) would represent the No-Go signal (the colours were counterbalanced across participants). Furthermore, they were told that they would be shown videos of a hand being stabbed by a needle or touched by a Q-tip before each visual cue. They were told to imagine "what the stimulated individuals might have felt" while watching the videos. After confirming that the participant understood the instructions, they were given 24 practice trials before beginning the main part of the experiment. The main part of the experiment consisted of 8 blocks of 60 trials each. Participants were given a self-paced break after each block. A single trial consisted of the following order of events: Fixation Cross (500ms) –> Video Stimuli (1800ms) –> Delay (None or 500ms) –> Go Signal (Until Response)/No-Go Signal (500ms or sooner if participant erroneously responds) –> ISI (500ms) (See Figure 4.1). Afterwards, the participants completed the IRI. Lastly, participants were debriefed about the purpose of the study before ending the experiment.

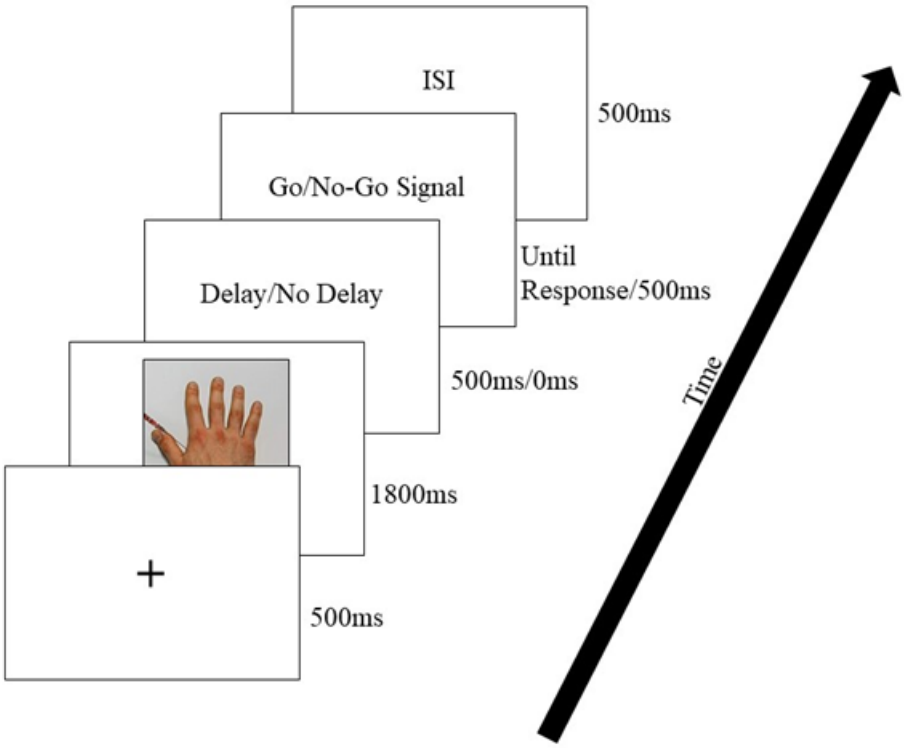

FIGURE 4.1: Schematic of a single trial in Experiment 1.

4.4.2 Results

Reaction Times

Average mean error (responding to the No-Go signal) rate was around 4.1%. Correct reaction times less than 150ms (anticipations) or greater than 1000ms (missed trials) were removed before final analysis (around 1%). The 2x2x2 repeated measures ANOVA yielded a significant main effect of Video Type [$F(1,59) = 49.8$, $p < 0.00001$, $\eta_p^2 = 0.46$], wherein participants responded faster after watching the Needle videos [$M = 416$ms, $SE = 8.35$] compared to Q-tip videos [$M = 427$ms, $SE = 8.42$] (See Figure 4.2a); a significant main effect of Movement Type [$F(1,59) = 60.8$, $p < 0.00001$, $\eta_p^2 = 0.51$], wherein participants responded faster when conducting a key press [$M = 400$ms,

SE = 7.78] compared to a key release [M = 443ms, SE = 9.67] (See Figure 4.2b); and a significant main effect of Delay [$F(1,59)$ = 486, $p < 0.0001$, $\eta_p^2 = 0.9$], wherein participants responded faster to the Go signal when it was presented with a 500ms delay [M = 390ms, SE = 8.03] compared to no delay [M = 453ms, SE = 8.89] (See Figure 4.2c). We also found a significant Movement Type x Delay Interaction [$F(1,59) = 60$, $p < 0.00001$, $\eta_p^2 = 0.48$]. This two-way interaction indicates that main effect of Movement Type (faster RTs for key presses vs. key releases) is weaker, but still significant, when the Go signal is presented with a 500ms delay [Key Release: M = 407ms, SE = 9.2; Key Press: M = 373ms, SE = 7.56; $t(59) = 6.45$, $p < 0.00001$, $d = 0.8$] compared to when it is presented with no delay [Key Release: M = 479ms, SE = 10.4; Key Press: M = 428ms, SE = 8.16; $t(59) = 8.7$, $p < 0.00001$, d = 1.2].

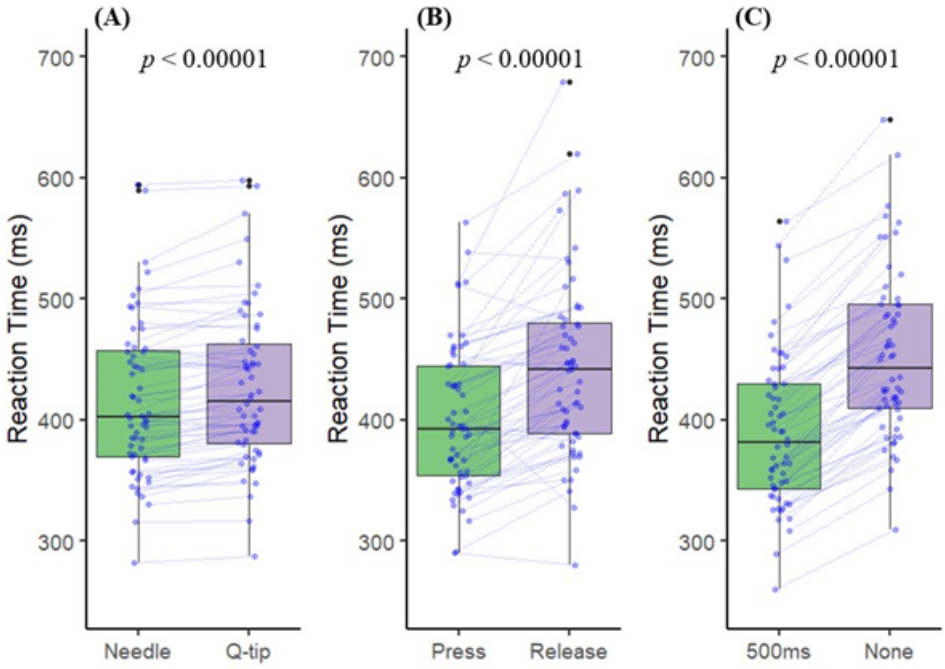

FIGURE 4.2: (A) Boxplot showcasing the main effect of Video Type (Needle vs. Q-tip). (B) Boxplot showcasing the main effect of Movement Type (Press vs. Release). (C) Boxplot showcasing the main effect of Delay (500ms, None). Each blue dot represents a single participant. The dotted line connects participant reaction times across conditions.

IRI

The IRI is broken down into 4 subscales: Perspective Taking (PT), Empathic Concern (EC), Fantasy Scale (FS), and Personal Distress (PD). As the only significant effect related to pain observation was a main effect of Video Type, we opted to take the difference score of reaction times across the collapsed Needle and Q-tip conditions and correlate this pain observation effect with each of the IRI subscales. One participant did not fully complete the IRI and, thus, was not included in this analysis. No significant correlations were found [all $p > 0.3$].

4.4.3 Discussion

Experiment 1 provides evidence for significant main effects of Movement Type, Delay, and Video Type. The main effect of Movement Type shows that participants responded significantly faster to the Go signal if they responded with a key press vs. a key release, which matches what Morrison et al. (2007b) reported. The main effect of Delay shows that participants responded significantly faster if the Go signal appeared after a 500ms delay (compared to no delay), which matches what Galang et al. (2017) reported. Crucially, the main effect of Video Type shows that participants responded significantly faster to the Go signal if it was preceded by a Needle video vs. a Q-tip video, which replicates previous work showing that pain observation leads to a general facilitation of motor responses (e.g., Galang et al., 2017; Galang and Obhi, 2020). We also report no significant correlations with the IRI subscales (discussed further in "General Discussion").

Note that, given the lack of a Video Type x Movement Type x Delay or a Video Type x Movement Type interaction, the results of experiment 1 offer no evidence to support the Natural-Mappings hypothesis (indeed, we report only a significant, but irrelevant to the Natural-Mappings hypothesis, Movement Type x Delay interaction effect). One possible reason for our failure to find evidence for the Natural-Mappings hypothesis is that the

key presses and releases may not have been accurate enough representations of approach and withdrawal behaviour. Of course, this does not explain how such movements yielded the significant results reported in Morrison et al. (2007b). Nevertheless, it is possible that having participants perform more naturalistic movements will lead to Movement Type modulation during pain observation. Experiment 2 tests this possibility.

4.5 Experiment 2

4.5.1 Methods

Participants

60 participants were recruited to participate in this study for course credit (male = 12; age = 18.2). One participant was removed and replaced due to voluntarily withdrawing halfway through the experiment, and another participant was removed and replaced due to making >95% error during the task. As we replaced both participants, our sample size remains at 60. Prior to participation, participants provided written informed consent. The study was approved by the McMaster Research Ethics Board (MREB).

Apparatus and Stimuli

Experiment 2 was similar to experiment 1; however, there were two important differences. First, rather than responding via the spacebar on a keyboard, participants in experiment 2 used a Joystick (Thrustmaster) to perform forward (approach) and backward (withdrawal) movements. Second, rather than completing a Go/No-Go task and alternating between key presses and releases per trial, we opted to cue participant Movement Type via a symbol (i.e., a circle or a hexagon - counterbalanced) that appeared before each video stimuli. Participants then made simple reaction time responses to an orange square.

Design

Experiment 2 followed the same 2x2x2 within-subjects design used in experiment 1. However, as participants no longer needed to alternate between key presses and releases every other trial, we could now randomize all fully crossed conditions (i.e., Needle-Forward-Immediate, Needle-Forward-500ms, Needle-Backward-Immediate, Needle -Backward-500ms, Q-tip-Forward-Immediate, Q-tip-Forward-500ms, Q-tip-Backward-Immediate, Q-tip-Backward-500ms) throughout the experiment. Participants completed 8 blocks of 40 trials, which included 40 trials per fully crossed conditions.

Procedure

Experiment 2 generally followed the same procedures as experiment 1. However, rather than being instructed on key presses and releases, participants were first trained to perform an approach or withdrawal movement with a joystick. At the start of the experiment, we instructed participants to either move the joystick forward if they saw one symbol (e.g., a circle) and move it backwards if they saw different symbol (e.g., a hexagon). We counterbalanced symbol-movement associations across participants. They were given 12 practice trials to get used to this association. The main part of the experiment consisted of 8 blocks of 40 trials each. Participants were given a self-paced break after each block. A single trial consisted of the following order of events: Forwards/Backwards Symbol (2000ms) –> Fixation Cross (1000ms) –> Video Stimulus (1800ms) –> Delay (None or 500ms) –> Response Cue (i.e., an orange square; until response) –> ISI (500ms) (See Figure 4.3). Participants completed the IRI before finishing the experiment.

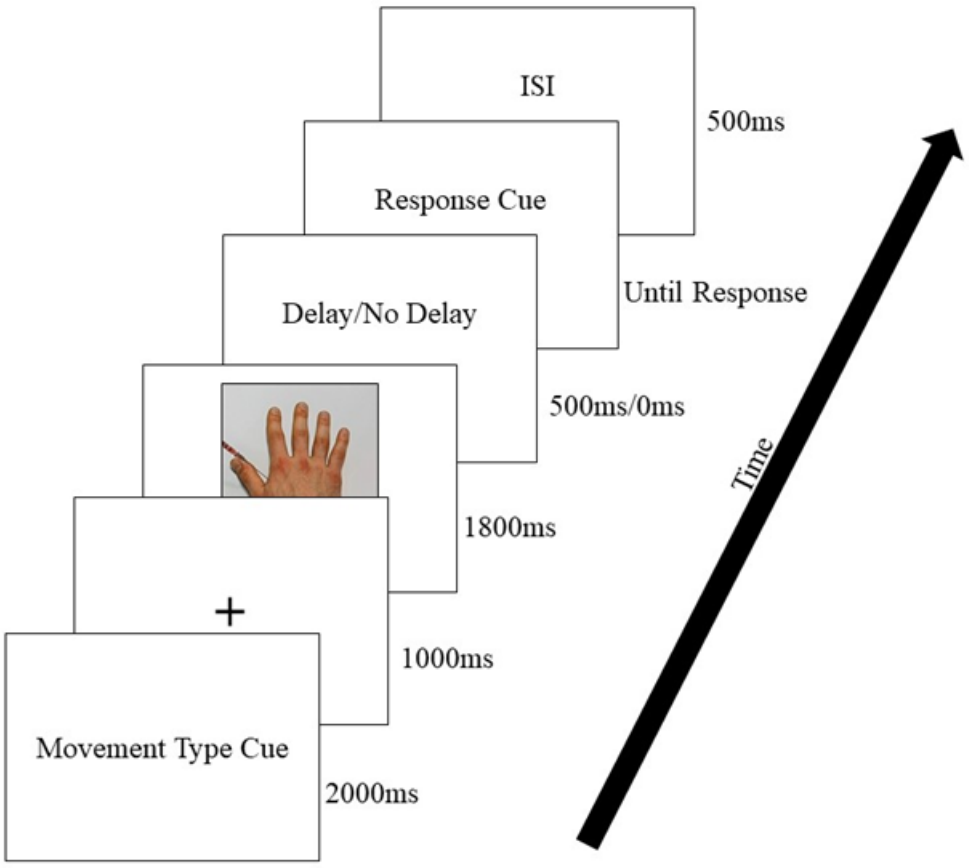

FIGURE 4.3: Schematic of a single trial in Experiment 2.

4.5.2 Results

Reaction Times

Average mean error (making the wrong movement type) rate was around 5.2%. Correct reaction times less than 150ms (anticipations) and greater than 1000ms (missed trials) were removed before final analysis (around 6.9%). The 2x2x2 repeated measures ANOVA yielded a significant main effect of Video Type [$F(1,59) = 26.9$, $p < 0.00001$, $\eta_p^2 = 0.31$], wherein participants made faster responses after viewing the Needle videos [$M = 483$ms, $SE = 9.19$] compared to Q-tip videos [$M = 495$ms, $SE = 9.04$] (See Figure

4.4a); a significant main effect of Movement Type [$F(1,59) = 20.9$, $p = 0.00002$, $\eta_p^2 = 0.26$], wherein participants made faster backward movements [$M = 482$ms, $SE = 8.43$] compared to forward movements [$M = 497$ms, $SE = 9.88$] (See Figure 4.4b); and a significant main effect of Delay [$F(1,59) = 623$, $p < 0.00001$, $\eta_p^2 = 0.91$], wherein participants made faster responses when the imperative cue was shown after a 500ms delay [$M = 442$ms, $SE = 8.6$] compared to no delay [$M = 536$ms, $SE = 9.8$] (See Figure 4.4c). We also found a significant Movement Type x Delay interaction [$F(1,59) = 11$, $p = 0.0016$, $\eta_p^2 = 0.16$]. This two-way interaction indicates that the main effect of Movement Type (faster backward movements compared to forward) is being driven primarily by the no delay condition [Forward: $M = 547$ms, $SE = 10.6$; Backward: $M = 525$ms, $SE = 9.2$; $t(59) = 5.9$, $p < 0.00001$, $d = 0.77$] compared to the 500ms delay condition [Forward: $M = 446.2$ms, $SE = 9.6$; Backward: $M = 438$ms, $SE = 8.1$; $t(59) = 1.94$, $p = 0.057$].

IRI

Following experiment 1, the only significant effect related to pain observation was a main effect of Video Type, and as such, we opted to take the difference score of reaction times across the collapsed Needle and Q-tip conditions[1] and correlate this pain observation effect with each of the IRI subscales. Three participants did not fully complete the IRI and, thus, were not included in this analysis No significant correlations were found [all $p > 0.23$].

4.5.3 Discussion

Experiment 2 yielded the same pattern of results as experiment 1: a significant main effect of Movement Type, which shows that participants made faster backward movements compared to forward movements; a significant main effect of Delay which shows that

[1]This was by first averaging reaction data involving either the Needle or Q-tip stimuli. Afterwards, the Needle reaction times was subtracted from the Q-tip reaction times.

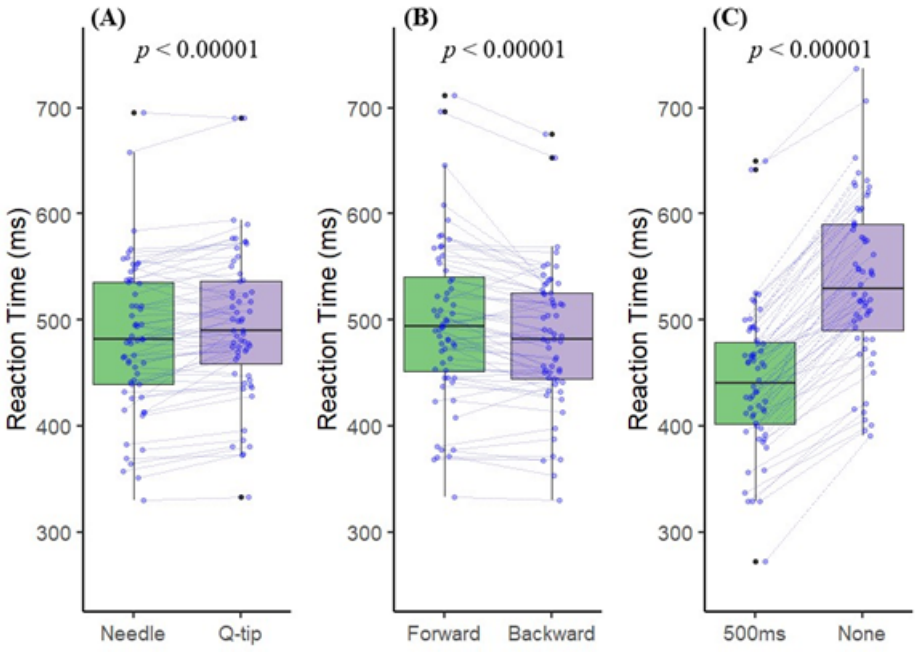

FIGURE 4.4: (A) Boxplot showcasing the main effect of Video Type (Needle vs. Q-tip). (B) Boxplot showcasing the main effect of Movement Type (Forward vs. Backward). (C) Boxplot showcasing the main effect of Delay (500ms, None). Each blue dot represents a single participant. The dotted line connects participant reaction times across conditions.

participants made faster overall movements if the response cue was delayed by 500ms (compared to no delay); and a significant main effect of Video Type, wherein participants made faster overall movements after observing the Needle videos vs. Q-tip videos. We again found no significant correlations with the IRI subscales (discussed further in "General Discussion"), and crucially, we found no evidence for the Natural-Mappings hypothesis (although we again found a significant Movement Type x Delay interaction effect).

4.6 General Discussion

The aim of the current study was to empirically test the Natural-Mappings hypothesis, which predicts that, when the option is available, pain observation should lead to slower approach-like movements and faster withdraw-like movements. Neither experiment 1 nor experiment 2 yielded data to support this hypothesis. Instead, the results corroborated recent work showing that pain observation leads to a response-general facilitation effect of motor behaviour (e.g., Galang et al., 2017; Galang and Obhi, 2020; Fabi and Leuthold, 2016). Given these results, we can now state with some confidence that pain observation does not lead to adaptive approach/withdraw movements. Thus, such adaptive behaviour cannot be used to explain the functional significance of motor facilitation after pain observation.

One possible explanation comes from work by Han et al. (2017), who has recently shown that motor facilitation as a result of pain observation, in the form of a stronger response force, may be functionally related to inducing self-distress relief via attenuating neural responses (specifically the bilateral secondary somatosensory cortex) associated with pain observation. Such a mechanism may enhance empathic experiences towards another in pain, as current models of empathy suggest that, to appropriately empathize with another, one must focus on the other's state and not confuse it with one's own (e.g., Bird and Viding, 2014). This self to other shift in attention may become easier if one's own distress is not distracting, and as such, having a mechanism to decrease one's own distress would be useful if one were attempting to empathize with another. It is important to note, however, that Han et al. (2017) had participants respond (and continue to respond) by pressing a key during pain observation, and their main dependent variable indexing motor facilitation was response force. As such, it is unclear whether motor facilitation, as indexed by reaction times, after pain observation provides the same self-relief mechanism.

The other line of thought comes from work showing that higher arousal levels can lead to faster reaction times (e.g., Martinie et al., 2010). As such, it is possible that the general motor facilitation effects seen in these (and previous) studies is primarily due to general arousal levels increasing while watching the Needle videos, which then leads to faster reaction times when responding to the imperative cue. However, it is important to note that high arousal does not always lead to faster reaction times. For example, work by De Houwer and Tibboel (2010) found that participants responded slower to a Go signal after observing a highly arousing image (both negatively and positively valanced). This comparison between De Houwer and Tibboel (2010) and motor facilitation after pain observation effects (e.g., Galang et al., 2017) is apt, as both use similar paradigms: in both cases, participants completed some sort of reaction time task (e.g., Go/No-Go Task), however, whereas previous motor facilitation after pain observation studies (e.g., Galang et al., 2017) showed videos of either a needle stabbing a hand or a Q-tip touching a hand before each imperative cue, De Houwer and Tibboel (2010) instead showed pictures from the International Affective Picture System (IAPS; Lang et al., 2008) (also see Verbruggen and De Houwer, 2007). They provide an attentional account of these results, pointing out that high emotional/arousing stimuli command more attentional resources, and as such, detract from attentional processing of a subsequent cue (e.g. a Go signal). As such, if our results were due to high arousal levels, we ought to have found slower reaction times after pain observation – given that we found the opposite, De Houwer and Tibboel (2010) results provide some evidence that the current results are not solely due to arousal levels.

It is also interesting to note that previous work in the emotion and attention literature has shown that positive-valenced and negative-valenced stimuli are mapped on to approach-like and withdraw-like movements, respectively (e.g., Duckworth et al., 2005; Warriner et al., 2017; Fini et al., 2020). As such, in addition to De Houwer and Tibboel (2010), the fact that the current experiments do not provide evidence for this mapping

emphasizes a discrepancy between the pain observation and emotion and attention literatures. One might wonder if the type of stimuli used in each paradigm plays a role in this discrepancy; whereas those in the latter use emotional pictures and words, those in the former prefer videos. However, note that previous work showing others in pain via a picture format have yielded the same motor facilitation after pain observation effects found in their video stimuli counterparts (e.g., Fabi and Leuthold, 2016; Fabi and Leuthold, 2018; Galang et al., 2020). As such, it is unlikely that the stimuli format is the key factor driving this discrepancy. Future work will be needed to shed light on this issue.

Regarding the lack of significant correlations between the IRI subscales and the motor facilitation effect found in both experiments – this finding corroborates what has been reported in previous work (Galang et al., 2017; Galang and Obhi, 2020). Note that one might argue that the lack of significant correlations is due to not having a sufficiently large sample size, and indeed, a sensitivity analysis via G*Power (Faul et al., 2007; Faul et al., 2009) shows that n = 60 is sensitive enough to detect $r = 0.3$ (medium effect size) at 65% power and $r = 0.2$ (small effect size) at 33% power. As such, there could possibly be an association that the current (and past) studies are not sensitive enough to detect. However, Hedge et al. (2018) have recently shown that cognitive tasks, such as the Go/No-Go task, are not well suited for correlation analysis, as cognitive tasks are designed to limit between-subjects variance, while trait measures emphasize between-subjects variance (also see Dang et al., 2020). This means that the former often have low internal reliability, which in turn leads to a higher chance of not finding (nor replicating) significant correlations. As such, it is possible that the behavioural tasks used in the current experiments (and past studies) are not suited to detect individual differences in trait levels of empathy. More work will be needed to further explore this topic.

It is also interesting to connect the current behavioural results with the neurophysiological indices of sensorimotor activity during pain observation (Riečanský and Lamm,

2019). One such measure is the use of TMS to explore cortico-spinal activity during pain observation – interestingly, this paradigm shows that there is a muscle-specific decrease in cortico-spinal activity during pain observation (e.g., Avenanti et al., 2005). This result contrasts with the motor facilitation effect reported in the behavioural literature; however, given that this reaction time effect occurs after pain observation, and the TMS effect occurs during pain observation, it is possible that there is a muscle-specific decrease in activity during pain observation which leads to a response-general motor facilitation effect after pain observation. However, EEG (electroencephalography) studies have found stronger desynchronization in the Beta and Mu frequency bands during pain observation (e.g., Yang et al., 2009; Fabi and Leuthold, 2016; Riečanský et al., 2015; Riečanský et al., 2020). As Beta and Mu desynchronization are thought to index increased motor and somatosensory activity, respectively, these results suggest that there is an increase in sensorimotor activity during pain observation. As such, while contrary to TMS studies, these results better match their behavioural counterpart: increased sensorimotor activity during pain observation leads to motor facilitation after pain observation. However, no work that we are aware of has explicitly explored the relationship between these measures and behavioural responses; and as such, future work will be needed to fully explicate this relationship. Furthermore, while we did not find evidence for the Natural-Mappings hypothesis at the behavioural level, it is possible that differential effects of approach-related and withdraw-related movements may be present at the neural level (Fini et al., 2020).

In conclusion, neither experiments reported in this study found evidence to support the Natural-Mappings hypothesis. Instead, participants showed a response-general effect of pain observation on motor behaviour, such that they responded faster after observing someone in pain (vs. no pain), regardless of movement type. Future work is needed to fully explicate the functional significance of this effect.

Chapter 5

To Move or Not to Move: Cortico-spinal activity is enhanced during pain observation regardless of motor preparation state

Galang, C.M. and Obhi, S.S. (In Prep.). To Move or Not to Move: Cortico-spinal activity is enhanced during pain observation regardless of motor preparation state.

5.1 Preface

The previous three chapters have shown that pain observation leads to a general and temporally extended motor facilitation effect, and that such facilitation is enhanced when participants are told to explicitly empathize. These results are in contrast to those reported in the TMS literature on sensorimotor resonance, wherein pain observation leads to a muscle-specific decrease in cortico-spinal activity and is influenced by the perceived level of pain (rather than instructions to empathize). In chapter 2, we speculated that such discrepancies may be due to the task instructions of each paradigm: in TMS studies participants are instructed to relax their hands, whereas in behavioural studies participants are necessarily in a state of perpetual readiness. However, given

the methodological differences across these paradigms, direct comparisons of results are hard to make. As such, the aim of the current chapter is to directly test this hypothesis. To do so, we created two conditions: in the passive condition, participants completed a normal TMS study on sensorimotor resonance, while in the active condition, participants also completed a simple reaction time task by responding to imperative cue after each video stimuli.

According to our hypothesis, we ought to see a decrease in cortico-spinal activity in the passive condition and an increase in the active condition. Contrary to our expectations, we instead found that regardless of condition, participants simply showed an increase of cortico-spinal activity during pain observation. We also did not find the motor facilitation effect reported in previous behavioural studies; however, this may have been due to the TMS interfering with the participants' movements (as TMS can cause visible muscle/finger twitches). While the results of this study are perplexing (as we do not replicate previous TMS studies on sensorimotor resonance), they better match the behavioural motor facilitation effects previously reported (as an increase in cortico-spinal activity ought to be indicative of faster response times). However, as we did not find this behavioural effect in this experiment, it was difficult to test whether they are correlated with cortico-spinal activity. As a final note, we specifically refer to sensorimotor resonance as measured via TMS as "empathic sensorimotor resonance" in this chapter. This was done primarily due to previous TMS studies referring to it as such (Avenanti et al., 2010).

5.2 Abstract

Previous TMS studies have shown that there is a decrease in cortico-spinal activity during pain observation. In contrast, recent behavioural studies have shown that response times are faster after pain observation. This suggests that there is a mismatch between

motor activity during vs. after pain observation. We hypothesized that this mismatch may be explained by task instructions, as participants in TMS studies are instructed to relax their hands while behavioural studies necessarily have participants in a state of perpetual readiness. However, methodological differences make comparisons between these paradigms difficult. As such, the aim of the current study is to directly test this relationship within a single experiment. To do so, participants watched videos of hands in painful vs. non-painful scenarios while TMS-induced motor evoked potentials were recorded. In the "Active" block, they responded to a cue that appeared immediately after each video; in the "Passive" block, they relaxed their hand. Contrary to our expectations, our results indicated that participants showed increased cortico-spinal activity during pain observation (vs. no-pain) in both blocks. We discuss these results in relation to the wider social neuroscience of empathy literature.

5.3 Introduction

Empathic sensorimotor resonance refers to the decrease in cortico-spinal activity that occurs as a result of watching another in pain (e.g., Avenanti et al., 2005; Avenanti et al., 2010). In a seminal study, Avenanti et al. (2005) provided initial evidence for this effect by having their participants observe videos of needles and Q-tips stabbing/touching a person's hand. Using Single Pulse Transcranial Magnetic Stimulation (TMS) and Electromyography (EMG) to measure Motor Evoked Potentials (MEP; an index of cortico-spinal activity) from the participants as they watched the videos, they found that participants showed a decrease in MEP amplitude when observing the needle stab the hand compared to the Q-tip. Furthermore, this effect was specific to MEP recorded from the first dorsal interosseous (FDI); this is important as the needle in the videos penetrated this same muscle and thus suggests a muscle localized effect. Given that a decrease in MEP amplitude is also seen during the first-person experience of pain (e.g. Farina et al., 2001), Avenanti et al. (2005) suggested that "[...] *the effect may be due to activation*

of a pain resonance system that extracts basic sensory aspects of the model's painful experience (such as source or intensity of a noxious stimulus) and maps them onto the observer's motor system according to topographic rules." (pg. 958). As empathy is often theorized as the result of shared/matching representations/neural activations (e.g., De Waal and Preston, 2017), Avenanti et al.'s (2005) result has often been thought of, along with other neurophysiological measures, as an important neurophysiological index of empathic processing towards others in pain (Neumann and Westbury, 2011; Betti and Aglioti, 2016; Riečanský and Lamm, 2019).

Further experiments have largely confirmed and/or extended Avenanti et al.'s (2005) original findings. For example, subsequent studies have found that empathic sensorimotor resonance is modulated by the perceived level of pain (i.e., showing a needle pinprick, as opposed to deeply stabbing, a hand; Avenanti et al., 2006) and imagined level of pain (i.e., how much the pain "spreads"; Minio-Paluello et al., 2006), is positively correlated with psychopathic tendencies (Fecteau et al., 2008) and trait and state levels of cognitive empathy (Avenanti et al., 2009a), is absent for participants with Asperger syndrome (Minio-Paluello et al., 2009), is influenced by racial bias (Avenanti et al., 2010), is attenuated when presenting videos a distance away (Mahayana et al., 2014) and when perceiving others in pain from the third-person perspective (Bucchioni et al., 2016), and reverses in the opposite (to the observed) hand (Avenanti et al., 2009b), reverses in participants with pain synesthetes (Fitzgibbon et al., 2012), reverses in participants trained to feel a sense of control over the hand in the videos (De Coster et al., 2014), and, lastly, reverses after decreasing self-other control (De Guzman et al., 2016). While more work is still needed to further elucidate the exact functional role of empathic sensorimotor resonance, it is nevertheless clear that cortico-spinal activity is modulated in some way when a person observes another in pain.

Although seldom studied compared to TMS studies, reaction times are sometimes used as a behavioural index of motor activity modulation as a result of pain observation

(e.g., Morrison et al., 2007b; Morrison et al., 2007a; Han et al., 2017; Fabi and Leuthold, 2016; Galang et al., 2017; Galang and Obhi, 2020; Galang et al., 2020). In this paradigm, participants are tasked with watching videos containing others in pain (vs a control); in addition, a subsequent imperative cue is presented after each video trial. In our recent behavioural work (Galang et al., 2017), we found that participants responded faster after watching the same Needle videos used by Avenanti et al. (2010). Furthermore, this occurred regardless if they were responding with their right index finger or foot, and both when the imperative cue appeared immediately after, or 500ms after, the video ended. This was contrary to our expectations as we expected the behavioural results to somewhat mirror the TMS results: slower reaction times (due to the decrease in MEP amplitude) that were specific to the area of observed pain (given the muscle specificity of the MEP effect).

In Galang et al. (2017), we put forward the idea that this apparent contradiction between the neurophysiological and behavioural results could be explained by the task instructions used in each paradigm. In TMS studies, participants are instructed to relax their hand as much as possible. This leads to a passive state in the motor system. In contrast, behavioural studies instruct their participants to be in state of perpetual readiness, as they must respond to an imperative cue as fast as they can. We thought it possible that, in a state of relaxation, pain observation could lead to the decrease in activity seen in most TMS studies, while in a state of perpetual readiness, pain observation could lead to an increase in activity as seen in our behavioural results. We refer to this as the State-Dependent Hypothesis. In order to test this hypothesis, the current study presents the first (as far as we are aware) TMS pain observation experiment wherein participants are also tasked with responding to a subsequent cue after pain observation.

To do so, participants observed others' in pain in two separate blocks. In one block (the "Active" block), participants were instructed to press an assigned key with their

right index finger as fast as they could after seeing an imperative cue (i.e., a coloured square). This cue appeared immediately after the video. The TMS fired during video observation. In this way, we can measure cortico-spinal activity during pain observation via the TMS and after pain observation via reaction times. In the other block (the "Passive" block), participants were instructed to relax their hand as much as possible and to do nothing when the cue appeared on the screen after each video. As such, this latter block matches the state of the participant in previous TMS studies.

Given this design, the State-Dependent Hypothesis predicts that participants will show a significant increase in MEP amplitude during pain observation (needle video) compared to no pain (Q-tip video) during the Active block; however, during the Passive block, the usual decrease in MEP amplitude should be seen during pain observation (vs no pain). Note that if the State-Dependent Hypothesis is incorrect, then we, at the very least, expect the find the usual empathic sensorimotor resonance effect reported in the literature (regardless of block type). Furthermore, in the Active block, participants should show faster response times after pain observation (vs. no pain); however, given that the TMS elicits overt and unintentional movements (e.g., finger/muscle twitches), it is possible that TMS stimulation will sufficiently disrupt button presses such that we no longer see this expected pattern of results.

As a final note, we made some methodological choices to give this study the best chance of eliciting the empathic sensorimotor resonance effect: first, we only recruited Caucasian participants – this choice was based on Avenanti et al.'s (2010) finding that racial-bias attenuates empathic sensorimotor resonance. In addition, we presented the same exact stimuli used in Avenanti et al. (2010), with a Caucasian hand getting stabbed or touched by a needle or Q-tip, respectively. We also used the same trial numbers per condition as those used in Avenanti et al. (2005) and Avenanti et al. (2010), as well as implemented the same trial-by-trial exclusion criteria (i.e., we excluded trials where EMG noise was sufficiently high relative to the MEP and when MEP amplitudes were less than

0.05mV). Lastly, based on Bucchioni et al.'s (2016) finding that empathic sensorimotor resonance is attenuated when TMS stimulation occurs early in the video stimuli (they used the same video stimuli used in this experiment), TMS stimulation was programmed to occur near the end of the video stimuli.

5.4 Methods

5.4.1 Participants

38 right-handed Caucasian participants participated in this study (male = 3; age = 18.47) for course credit. Sample size was determined via a simulation-based power analysis (e.g., via the SuperPower (ver. 0.0.3) R package; Lakens and Caldwell, 2019) showing that, for a 2x2 Repeated Measures Interaction Effect, n = 38 is sensitive enough to detect $\eta_p^2 = 0.2$ at 80% power. This effect size estimate is, admittedly, rather arbitrary; however, note that other 2x2 Repeated Measures Interaction Effects found in the literature report $\eta_p^2 = 0.53$ (Avenanti et al., 2009b) and $\eta_p^2 = 0.44$ (Mahayana et al., 2014). As such, our estimate is comparatively conservative. Furthermore, as the average sample size (per cell) in the literature is n = 20 (based on the reviewed literature presented in the introduction), the current sample size should also be sufficiently powered to find the basic effect of empathic sensorimotor resonance. Prior to participation, participants provided written informed consent. This study was approved by the Hamilton Integrated Research Ethics Board (HIREB).

5.4.2 Apparatus and Stimuli

We used short videos developed by Avenanti et al. (2010) depicting a Caucasian hand being stabbed by a needle or lightly touched by a Q-tip on the area of skin overlaying the first dorsal interosseous (FDI). Each Video Type (Needle vs. Q-tip) consisted of three separate videos with the colour of the syringe and Q-tip handle varying. As per

Avenanti et al. (2010), this was done to minimize effects of habituation. The experiment was programmed and presented using SuperLab v4.5 (Cedrus Corporation, San Pedro, CA, USA) and was run on a Lenovo P910 ThinkStation. Participants responded with their right index finger using a Cedrus RB series Response Pad. The signals used for the reaction time task was an Orange square. Electromyography (EMG) data was recorded using an MP150 data acquisition system (Biopac Systems). One ground electrode was placed on the participants right elbow, and two surface electrodes were placed in a over the participant's first dorsal interosseous (FDI). The EMG signal was acquired with a 5 kHz sampling rate, amplified (to 5 mV), and band-pass filtered at 10–500 Hz. A figure-eight coil connected to a Magstim Magnetic Stimulator was placed over the left motor cortex. The coil was moved over the left hemisphere to determine the optimal position from which maximal MEP amplitude were elicited in the FDI. The intensity of magnetic pulses was set at 130% of the Resting Motor Threshold (RMT), defined as the minimal intensity of the stimulatory output that produces MEP with an amplitude of at least 0.05 mV with 50% probability (average RMT = 36.6%).

5.4.3 Design

The experiment used a 2x2 Repeated Measures design wherein Video Valence (Needle, Q-tip) and Motor State (Active, Passive) were the factors. The experimental session was split into two blocks, with some participants randomly assigned to start with the Active block while others with the Passive block (counterbalanced). Each block contained a total of 36 trials, with the Needle and Q-tip videos randomly shown in each block. This leads to 18 trials per experimental condition (i.e., Active Needle, Active Q-tip, Passive Needle, Passive Q-tip; note that this follows Avenanti et al.'s (2005) original design). Furthermore, to obtain baseline cortico-spinal activity levels, we presented 36 trials of a still picture of the hand used in the video stimuli (with the Needle and Q-tip edited out of the picture) – 18 trials were shown at the start of the experiment, and 18 trials at the

end. This leads to two baseline blocks at the start and end of the experiment, with the Active and Passive blocks completed in between (e.g., Baseline Block –> Active Block –> Passive Block –> Baseline Block).

The trial-by-trial design was as follows: first, participants observed a fixation cross for 1000ms; afterwards, the Needle/Q-tip stimulus were presented (1800ms). Afterwards, the video stimulus would be erased and replaced with an orange square. In the Active Block, participant had to respond to the orange square by pressing an assigned button with their right index finger. In the Passive Block, participants were told to simply relax their hand throughout the block, and as such, the orange square disappeared after 500ms in this block. Lastly, a 7200 ISI was presented until the start of the next trial. TMS stimulation occurred during the video stimulus (randomly at 1600ms, 1650ms, 1700ms, 1750ms, or 1800ms after video onset). See Figure 5.1.

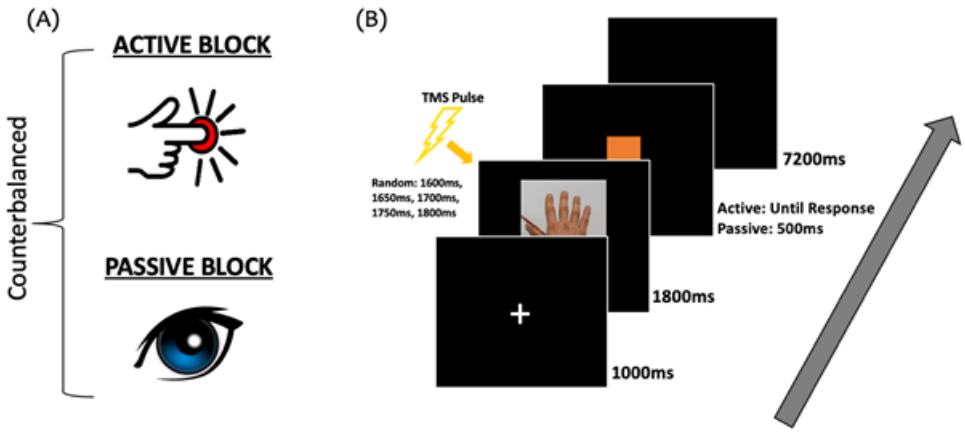

FIGURE 5.1: (A) Graphic of Active and Passive Block, with an emphasis on counterbalancing which block participants start the experiment with. (B) Single trial breakdown of the experiment.

5.4.4 Procedure

Participants first read over a letter of information and signed a consent form. Afterwards, two electrodes were placed over the FDI muscle of the participants right hand, with the

ground electrode placed on their right elbow. Next, participants were given a swim cap (used for markings) and measurements of their head size was taken to localize the vertex. Once the vertex was found, a mark was placed 5cm left and 2cm forward of the vertex – this mark was used for the initial coil position. After some initial TMS stimulations, the coil was moved over the left hemisphere to determine the optimal position from which maximal MEP amplitudes were elicited in the FDI. The RMT was then found by lowering the stimulator output until MEP amplitudes were close to 0.05mV (and could be elicited with at least 50% probability). Stimulator output was set at 130% of the participant RMT for the experiment. Once this was done, the TMS coil was placed in a magic arm super clamp to hold it in place. Participants were told to find a comfortable position and to minimize head movements throughout the experiment.

After equipment set up was complete, participants were given a pillow to rest their right hand on. They were told that they would see a picture of a hand, and that the TMS would be triggered while they observed the hand. After these baseline trials, participants either began the Active Block or Passive Block. Participants randomly assigned to start with the Active Block were told that they would see videos of a Needle or Q-tip stabbing or touching a hand, respectively, and that they should do their best to pay attention and "imagine what the stimulated individual is feeling" (instructions based on Avenanti et al. (2005)). Furthermore, they were told that an orange square would appear after each video. They were instructed to place their hand on a response pad, and to use their right index finger to press a button as faster as they could the moment they saw the orange square. In contrast, participants randomly assigned to start with the Passive block were told the same instructions; however, they were given a pillow to rest their hand on and were told to simply relax their hand throughout the experiment. At the end of the initial block, participants would then complete the opposite block. Lastly, participants completed another baseline block.

Participants were then instructed to remove the electrodes and swim cap (while the

experimenter turned off and put away the TMS). Before being debriefed to the purpose of the study, participants completed the Interpersonal Reactivity Index (IRI; Davis, 1980; Davis, 1983) – a self-report inventory used to measure trait-levels of empathy. The IRI is split into four subscales: Perspective Taking (PT), Empathic Concern (EC), Fantasy Scale (FS), and Personal Distress (PD). PT reflects the tendency or ability to adopt the point of view of other people, EC reflects the tendency to experience feelings of warmth, compassion and concern for others undergoing negative experiences, FS reflects the tendency to transpose or identify strongly with fictional characters (in movies, plays, books, etc.), and lastly, PD reflects the amount of discomfort and anxiety that occurs as a result of observing the negative experiences of others.

5.4.5 Data Processing

MEP trials which contained sufficient EMG background noise[1] (around 1.45%) or contained a peak-to-peak amplitude less than 0.05 mV (around 1.15%) were removed before final analysis. The remaining trials were then sorted by condition (Active Needle, Active Q-tip, Passive Needle, Passive Q-tip, Baseline 1, Baseline 2). As both Baseline conditions did not significantly differ ($p > 0.9$), MEP trials in the Baseline 1 and Baseline 2 blocks were averaged together to create an overall Baseline condition. The MEP peak-to-peak amplitudes in each non-baseline condition were then normalized to each participant's overall baseline activity via the following formula: ((MEP Amplitude / Baseline) * 100) - 100. As such, positive and negative numbers indicate % increase and % decrease relative to Baseline activity, respectively.

[1]This was determined by comparing the MEP peak-to-peak amplitude of the trial with the average peak-to-peak amplitude of EMG activity 500ms before the TMS pulse; if the former was within 3 standard deviations of the latter, then the trial was categorized as "EMG noise" and thus removed before final analysis.

5.5 Results

5.5.1 Cortico-Spinal Activity

The 2x2 Repeated Measures ANOVA yielded a significant main effect of Picture Valence [$F(1, 37) = 13.3$, $p = 0.0008$, $\eta_p^2 = 0.26$], wherein larger MEP amplitudes (relative to baseline) were observed during the Needle videos [$M = 59.6\%$, $SE = 11.8$] compared to the Q-tip videos [$M = 43\%$, $SE = 11.8$] (see Figure 5.2a). We also found a main effect of Motor State [$F(1,37) = 13.6$, $p = 0.0007$, $\eta_p^2 = 0.27$], wherein larger MEP amplitudes (relative to baseline) were observed in the Active Block [$M = 93.9\%$, $SE = 16.4$] compared to the Passive Block [$M = 8.8\%$, $SE = 16.4$] (see Figure 5.2b). The Motor State x Video Valence interaction did not reach significance [$p > 0.3$][2].

5.5.2 Reaction Times

The paired-samples t-test between Needle and Q-tip conditions did not yield a significant result [$p > 0.57$].

5.5.3 Correlations

Given the main effect of Video Valence, we opted to correlate scores on each IRI subscale (Perspective Taking (PT), Empathic Concern (EC), Fantasy Scale (FS), and Personal Distress (PD)) with the difference between Needle and Q-tip conditions. We found no significant correlations [all $p > 0.16$].

5.6 Discussion

The State-Dependent Hypothesis predicts that pain observation will elicit larger cortico-spinal activity (indexed via MEP) when the motor system is in a state of readiness to

[2]To make sure that our results are not dependent on our data processing steps, we also conducted analysis on the raw MEP values. The results do not significantly change from those reported with the normalized MEP values.

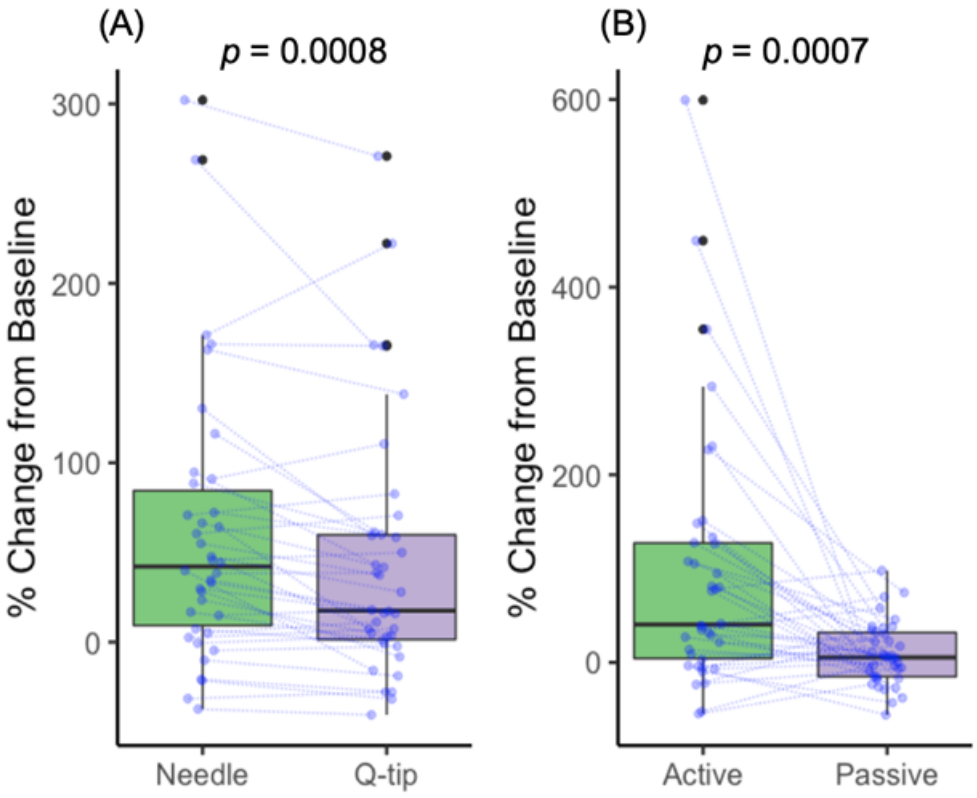

FIGURE 5.2: (A) Boxplot of comparing Needle vs. Q-tip results (collapsed across Motor State). (B) Boxplot of Active vs. Passive results (collapsed across Video Valence). Each blue dot represent participant % Change from Baseline scores. The blue dotted lines connect participants cores across conditions.

act; in contrast, pain observation should elicit smaller cortico-spinal activity when the motor system is in a state of rest. The current results do not match these predictions. Instead, we found that pain observation (relative to no pain) elicited larger cortico-spinal activity regardless of motor system state. Not only does this finding not support the State-Dependent Hypothesis, it also runs contrary to what is usually found with empathic sensorimotor resonance (i.e., smaller cortico-spinal activity during pain observation). Within the empathic sensorimotor resonance literature, we know of four studies that explicitly report larger cortico-spinal activity during pain observation. To better

contextualize the results of the current study, we briefly describe and discuss each of these studies in turn.

An early study by Avenanti et al. (2009b) found that, when measuring MEP in the observers opposite (to the hand in the video stimuli) hand, larger cortico-spinal activity occurs during pain observation. Of course, given the fact that we explicitly measured MEPs in the congruent hand, Avenanti et al. (2009b) finding cannot explain the results of the current study.

Next, Fitzgibbon et al. (2012) compared empathic sensorimotor resonance effects between a pain synesthete and a healthy control group. They found that, regardless of group, larger cortico-spinal activity was elicited during pain observation. Fitzgibbon et al. (2012) suggest that, "*It is possible that there is some variability in the reported inhibitory response between individuals, with some individuals showing facilitation, and that we had more of these individuals in the present sample. Mechanisms that may underlie such variation are unknown and warrant future investigation.*" (Pg. 412). Following this logic, it is also possible that the current study, just by chance, had a large number of individuals that happen to show facilitation effects.

Two possible sources for the mechanism that might explain such individual differences is provided by De Coster et al. (2014) and De Guzman et al. (2016). De Coster et al. (2014) found that training participants to feel like they had control over the hand in the observed video stimuli led to an increase in cortico-spinal activity during pain observation. In contrast, participants trained to feel like they no control over the observed hand led to the usual decrease in cortico-spinal activity during pain observation. As such, De Coster et al. (2014) suggest that one's sense of control over the observed hand is the key in predicting whether a participant will exhibit larger or smaller cortico-spinal activity during pain observation. De Guzman et al. (2016) add to this finding by showing that self-other control can also lead to differential modulation of cortico-spinal activity

during pain observation. Using the imitation-inhibition training paradigm (Santiesteban et al., 2012), De Guzman et al. (2016) randomly assigned participants into a "decrease" or "increase" self-other control condition. They found that increasing self-other control led to the usual empathic sensorimotor resonance effect (i.e., smaller cortico-spinal activity during pain observation); in contrast, decreasing self-other control led to larger cortico-spinal activity during pain observation. As such, they suggested that self-other control may be possible factor in predicting whether a participant will exhibit larger or smaller cortico-spinal activity during pain observation

As the current study did not measure levels of sense of control nor self-other control, it is possible that our participants happen to have felt a high degree of sense of control and/or are pre-disposed with low self-other control. This would then explain why we found larger cortico-spinal activity during pain observation, regardless of motor state group. Of course, given that we did not specifically manipulate their sense of control/self-other control, and neither have other studies, it is odd that we found the results that we did. Furthermore, it is possible that neither sense of control nor self-other control are responsible for the current results, and other yet to be discovered factors are at play. More work will be needed to fully answer this question.

In addition to a possible third-variable influencing our results, one might also wonder if carry over effects may be the cause of not finding the usual empathic sensorimotor resonance effect in the Passive block; that is to say, perhaps starting with the Active block sufficiently put the participants' motor state into a "ready to move" mode which then carried over in the Passive block. To test this possibility, we analyzed data from participants that started with the Passive block exclusively with data in the Passive block. We again found larger cortico-spinal activity during pain observation vs. no pain [$p = 0.017$]. As such, carry-over effects cannot explain the current results.

One may also contest that individual differences in trait-empathy may be the reason

why we do not find the usual empathic sensorimotor resonance effect. Indeed, De Guzman et al. (2016) exclusively tested participants that scored 13 or lower on the Personal Distress subscale of the IRI (as higher levels of PD seem to attenuate empathic sensorimotor resonance; Avenanti et al., 2009a). To test this possibility, we analyzed data from participants that scored 13 or lower on the PD subscale (n = 27). We again found larger cortico-spinal activity during pain observation vs no pain [$p = 0.007$]. As such, and addition to the lack of significant correlations with the IRI subscales reported in this study, individual differences in trait-empathy cannot explain the current results.

In regards to the reaction time results, we did not see faster responses after the Needle videos compared to the Q-tip. While this result is contrary to our previous findings (Galang et al., 2017; Galang and Obhi, 2020), it is also not surprising – as discussed in the introduction, single pulse TMS elicits an overt behavioural twitch that is quite noticeable (e.g., finger twitches) to the participant. This twitch may have been strong enough to disrupt the effects of pain observation on reaction times, especially considering the fact that we aimed to explicitly stimulate the FDI, which is a muscle that mediates index finger movement.

As a final comment, it is interesting to note that, while the current results are contrary to what is usually found within the empathic sensorimotor resonance literature, it is congruent with another neurophysiological index of empathy for pain: mu and beta suppression. Mu and Beta suppression refers to the event-related decrease in 7-12Hz and 13-30Hz activity, respectively, measured from electrodes overlaying the motor and somatosensory cortices – in the empathy for pain literature, mu and beta suppression have been shown to occur during pain observation (relative to no pain; e.g., Cheng et al., 2008; Yang et al., 2009; Riečanský et al., 2015; Riečanský et al., 2020; Fabi and Leuthold, 2016). Importantly, mu and beta suppression are an index of increased sensorimotor activity. As such, the decrease in cortico-spinal activity during pain observation, that is the defining feature of empathic sensorimotor resonance, is contrary to the mu/beta

suppression effect; however, the current results are not. In their recent review, Riečanský and Lamm (2019) point out that methodological differences between TMS and EEG studies make it difficult to compare across paradigms, and as such, future work should consider the use of combined methods (e.g., Joint TMS-EEG) to fully explore this topic.

In summary, the current study sought to test the State-Dependent Hypothesis of empathic sensorimotor resonance. Our results were inconclusive, as we did not find differential effects of pain observation on cortico-spinal activity as a result of motor preparation state; instead, we found a significant increase in cortico-spinal activity regardless of motor preparation state. We also note that, while the current results do not corroborate previous work on empathic sensorimotor resonance, the current results appear to be in line with another neurophysiological index of empathy for pain: Mu and Beta suppression. Overall, more work will be needed to fully elucidate both the directional effect of empathic sensorimotor resonance and its relation to other neurophysiological indices of empathy for pain.

Chapter 6

Motor preparation during pain observation does not influence event-related Mu/Beta desynchronization

Galang, C.M., Jenkins, M., Sanders, T., Vijh, R., and Obhi, S.S. (In Prep.). Motor preparation during pain observation does not influence event-related Mu/Beta desynchronization.

6.1 Preface

This chapter extends the previous chapter by measuring sensorimotor resonance via Mu and Beta desynchronization. An added benefit of using EEG is that, unlike TMS, it does not cause any visible finger/muscle twitches; as such, we ought to replicate the previously reported motor facilitation effect in this experiment. This then allows us to correlate the magnitude of the sensorimotor resonance effect with the reaction time effect. Following the previous chapter, we split the experiment into two conditions: passive (no movements) and active (keypresses in a Go/No-Go task). As Mu and Beta desynchronization is functionally related to an increase in sensorimotor activity, we expected to find such an increase in both passive and active conditions; however, we hypothesized

that motor preparation in the active condition would modulate this activity. Furthermore, we hypothesized that the magnitude of the sensorimotor resonance effect would positively correlate with the magnitude of the reaction time effect, thus linking overt motor behaviours with its sensorimotor precedents. Contrary to our expectations, motor preparation did not influence Mu/Beta desynchronization; rather, we simply found stronger desynchronization during pain observation (vs. no pain) regardless of condition. Furthermore, although participants did indeed show faster response times after pain observation (vs. no pain), this effect did not correlate with the Mu and Beta effects. The results of this experiment corroborate the previous chapters' results: motor preparation does not seem to influence sensorimotor activity during pain observation. Furthermore, we did not find evidence for an association between sensorimotor resonance and overt motor behaviours after pain observation.

6.2 Abstract

Previous EEG research has shown that there is an increase in sensorimotor activity, as indexed by Mu (7-12Hz) and Beta (13-30Hz) desynchronization, during pain observation. Such activity is usually taken as a measure of empathic processing, specifically in regard to the shared representations hypothesis, which states that empathy may arise as a result of shared neural activation between the subject and object of empathy. However, previous research using Mu and Beta desynchronization have primarily done so while participants are instructed to remain still. As pain observation often occurs in situations where the observer may be preparing an action (e.g., to help), an outstanding question is whether motor preparation influences sensorimotor activity during pain observation. The aim of the current study is to answer this question. To do so, participants observed videos and pictures of a hand getting stabbed by a needle or touched by a Q-tip. To manipulate motor preparation, in half the blocks, participants responded to a Go signal at the end of each needle/Q-tip stimulus, while in the other half, they

were instructed to stay still and passively observe the stimuli. The results showed no evidence of motor preparation influencing sensorimotor activity during pain observation; instead, we corroborate previous work and show larger Mu and Beta desynchronization during pain observation vs. no pain. Results also showed that such effects do not seem to correlate with reaction times (after pain observation) and trait-levels of empathy and does not seem to interact with trait-levels of vicarious pain experiences. Overall, the current study shows the robustness of sensorimotor activity during pain observation and highlights the need for more work in connecting such activity to empathic processing.

6.3 Introduction

Empathy, the ability to both understand and share the thoughts and emotions of others, is a fundamental part of the human condition. In the past decade and a half, social cognitive neuroscientists have made great strides in uncovering the neurobiological basis of empathy (for recent reviews, see: Betti and Aglioti, 2016; De Waal and Preston, 2017; Heyes, 2018; Tremblay et al., 2018; Riečanský et al., 2019). One fruitful line of research has been the use of Mu (7-12Hz) and Beta (13-30Hz) oscillations to study sensorimotor activity during empathic pain observation (Riečanský and Lamm, 2019).

In a seminal study, Cheng et al. (2008) used MEG to show that there is an event-related desynchronization (ERD) in the Mu frequency band during pain observation (vs. no pain). Mu ERD has been shown to be an index of somatosensory activity (Pfurtscheller and Lopes Da Silva, 1999), and is sensitive to both action execution and observation (e.g., Babiloni et al., 2002; Avanzini et al., 2012; Hogeveen et al., 2015). This matching between perception and action constitutes the theoretical thrust of the widespread Perception-Action Model of Empathy (PAM), which states that perception-action coupling is the mechanism by which people understand other's emotional states (Preston and De Waal, 2002; De Waal and Preston, 2017). Furthermore, such matching

has also led to a number of researchers to use Mu ERD as an index of human mirror neuron activity (Fox et al., 2016; but also see Hobson and Bishop, 2016; Hobson and Bishop, 2017).

Given this, and the fact that Cheng et al. (2008) also report that the strength of the relative ERD between pain and no pain conditions negatively correlated with the perspective taking subscale of the Interpersonal Reactivity Index (such that stronger relative ERD was associated with higher self-reported perspective taking ability; Davis, 1980; Davis, 1983), Cheng et al. (2008) concluded that, "*The results of our MEG study indicate that empathy for pain modulates neural activity in primary somatosensory cortex and supports the idea that the mirror-neuron system is important for empathizing with others by simulating their actions onto one's own sensory-motor representations*" (pg. 1838).

Follow-up studies have largely confirmed Cheng et al.'s (2008) primary results, although the use of EEG, rather than MEG, has been more popular. For example, Yang2009 used EEG to measure Mu ERD in male and female participants while they observed another person in pain vs. no pain. Their results showed that, regardless of gender, participants showed stronger ERD in the pain observation condition compared to no pain. Perry et al. (2010) used EEG to show that Mu ERD during pain observation can be attenuated by making the observed person dissimilar from the participant (i.e., by telling participants that the dissimilar person feels pain from Q-tips and not from needles). Using MEG, Whitmarsh et al. (2011) corroborated previous work showing that Mu ERD is stronger during pain observation vs. no pain; however, they also report a trend in the Beta (13-30Hz) frequency band. As Beta ERD has been shown to be an index of motor activity (Pfurtscheller and Lopes Da Silva, 1999), Whitmarsh et al.'s (2011) results suggest that both somatosensory and motor processing may be involved during pain observation.

While Whitmarsh et al.'s (2011) results merely showed a trend in the Beta frequency band, more recent work has established ERD in both Mu and Beta during pain observation (Riečanský et al., 2015; Riečanský et al., 2020; Grice-Jackson et al., 2017; Fabi and Leuthold, 2016; Fabi and Leuthold, 2018). Riečanský et al. (2015) reports that Beta ERD during pain observation is attenuated when observing a member of a racial out-group in pain; however, Mu ERD occurred regardless of the observed person's racial background (but see Fabi and Leuthold, 2018). Taking an individual-differences approach, Grice-Jackson et al. (2017) categorized their participants as "Non-Responders", "Affective-General Responders" (i.e., had a location-general and affective-based response during pain observation) , and "Sensory-Localized Responders" (i.e., had a location-similar and sensory-based response during pain observation), via the Vicarious Pain Questionnaire. They report a significant difference between pain observation vs. no pain in both Mu and Beta; however, they showed that this effect was primarily driven by the Sensory-Localized Responder group. Fabi and Leuthold (2016) measured event-related potentials (ERPs), Mu and Beta ERD, and behavioural motor responses all within a single experiment. They concluded that empathy-inducing stimuli produces automatic and controlled effects in perceptual (N240), categorization (P3), and motor processing (Mu/Beta ERD; faster RT and stronger responses force after pain observation vs. no pain) stages. Lastly, Riečanský et al. (2020) has recently shown that increasing self-other overlap (i.e., by having the presentation screen placed above the participants hand) increases the strength of Mu and Beta ERD during pain observation (vs. no pain).

The aim of the current study is to add to this growing line of research by exploring the role of motor preparation on Mu and Beta ERD during pain observation. Preparing actions while observing another in pain is not an uncommon occurrence (especially if one is a health worker). Motor preparation also plays an important part in the first-person experience of pain (e.g., avoiding pain, responding to pain, etc.; Morrison et al., 2013). As such, instructing participants not to move during Mu and Beta ERD experiments,

which is often the case, may create an artificial, or at least constrained, scenario that does not fully capture the range of possible reactions a person might have when they observe another person in pain. And as Mu and Beta ERD are often treated as potential indices of empathic processing, it behooves researchers to explore how such effects are influenced when participants are given less restrictions. While not as commonly studied as the neural correlates of empathy for pain, there have been some behavioural work exploring how explicit motor behaviour is influenced by pain observation.

For example, previous research has shown that observing another person in pain (vs. no pain) leads to a response general and temporally extended facilitation effect on reaction times (Galang et al., 2017). In this paradigm, participants complete a Go/No-Go task interleaved between stimuli depicting someone in pain vs. no pain. Galang et al. (2017) reported that participants responded faster to Go signals after pain observation (vs. no pain), regardless of whether they responded with their right index finger or foot and whether the Go signal was presented immediately after the stimuli or with a 500ms delay (also see Morrison et al., 2007a; Morrison et al., 2007b). Follow-up work showed that this reaction time effect is accentuated when participants are explicitly given instructions to empathize with the person depicted in the stimuli (Galang and Obhi, 2020).

Further work by Han et al. (2017) has shown that motor facilitation, in the form of a stronger continuous response force, occurs during the observation of video stimuli depicting another in pain. As response force negatively correlated with neural activation in the secondary somatosensory cortex (such that stronger response force correlated with less cortical activity), and given that this relationship was strongest in participants whom scored high on trait-levels of personal distress, they suggested that motor facilitation as a result of empathic pain observation may be functionally related to self-distress relief. Such a mechanism may enhance empathic experiences towards another in pain, as current models of empathy suggest that to appropriately empathize with another, one must focus

on the other's state and not confuse it with one's own (e.g., Bird and Viding, 2014). This self to other shift in attention may become easier if one's own distress is not distracting, and as such, having a mechanism to decrease one's own distress would be useful if one were attempting to empathize with another.

While most research using Mu and Beta ERD have not incorporated explicit motor behaviours in their study design, an exception is work done by Fabi and Leuthold (2016) and Fabi and Leuthold (2018) wherein participants completed a categorization task during the experiment; the fact they report Mu and Beta ERD due to pain observation may suggest that motor preparation does not influence such effects. However, without an appropriate control condition (no motor preparation) to compare to within the same experiment, it remains to be seen whether their effects show an attenuated or even accentuated ERD effect. This is especially the case given that their stimuli were shown for 200ms, which may not be enough time for motor preparation to fully influence neural processes related to empathic pain observation.

To explore this question, we combined methods used in previous behavioural studies (Galang et al., 2017; Galang and Obhi, 2020) with those commonly used in ERD studies (e.g., Riečanský et al., 2015; Riečanský et al., 2020). As we had access to the same stimuli set used by Riečanský et al. (2015) and Riečanský et al. (2020), which consisted of videos showcasing a hand getting stabbed by a needle or touched by a Q-tip (originally used in Avenanti et al., 2010), we opted to follow their paradigm. Specifically, in each trial, participant first observed a still picture of the hand in the video with the needle or Q-tip edited out of the frame. Afterwards, the needle or Q-tip would appear and would subsequently stab or touch the hand, respectively. Lastly, the last frame of the video was presented as a still picture depicting maximal needle penetration / Q-tip touch. To directly compare motor preparation within the same participant, in half the blocks, participants complete a Go/No-Go task with coloured squares acting as the imperative cues. These squares appeared immediately after the end of the maximal

needle penetration / Q-tip touch pictures. Note that having participants perform a Go/No-Go task puts them in a state of perpetual readiness to move and provides the task with enough difficulty to keep their attention. In the other half, participants were told to simply relax their hands and observe the stimuli. In these blocks, the squares were still shown (to match across conditions) but disappeared on their own after 500ms.

We can make a number of predictions based on the reviewed literature. First, given Han et al.'s (2017) results showing that motor behaviour reduces cortical activity in the somatosensory cortex, it is possible that preparing an action during pain observation will have similar effects on Mu ERD (less ERD). If we take a more general stance, we may also predict that Beta ERD will be similarly affected. Further support for this attenuation hypothesis comes from Riečanský et al. (2020), who showed that increasing self-other overlap leads to stronger ERD effects in both Mu and Beta. Given that motor preparation of one's own action may weaken one's simulation of the observed pain (and thereby decrease self-other overlap), this would predict that motor preparation will attenuate Mu and Beta ERD during pain observation. Of course, whether motor preparation will completely attenuate, or merely reduce the strength, of ERD effects remains to be seen. If motor preparation does not affect ERD in either frequency bands, and given the use of the same stimuli set and experimental procedures, we at the very least expect to corroborate Riecansky et al.'s (2015) original results: Beta ERD, but not Mu, due to pain observation should be observed during the video stimuli; and Mu ERD, but not Beta, due to pain observation should be observed during the static picture depicting maximal needle penetration. Lastly, we also predict that participants will show faster reaction times after pain observation (vs. no pain), corroborating previous behavioural results (e.g., Galang et al., 2017; Galang and Obhi, 2020). Furthermore, if Mu and/or Beta ERD is functionally related to reaction time facilitation, then we ought to see a significant correlation between the strength of ERD and reaction time effects.

It should be noted that, in addition to the primary question laid out above, we also

had participants complete the vicarious pain questionnaire (VPQ). As described, Grice-Jackson et al. (2017) report that Mu and Beta ERD due to pain observation is solely driven by participants categorized as "Sensory-Localized Responders". As such, as a secondary research goal, we aimed to see if we could corroborate Grice-Jackson et al.'s (2017) findings. Lastly, we also had participants complete the Interpersonal Reactivity Index (IRI; Davis, 1980; Davis, 1983). This was done to see if trait-levels of empathy correlated with Mu and Beta ERD due to pain observation as reported in previous research (e.g., Cheng et al., 2008).

6.4 Methods

6.4.1 Participants

84 right-handed participants (mean age = 18.5; female = 56) from the McMaster Psychology participant pool were initially recruited for course credit. Due to technical difficulties regarding the EEG, 2 participants were removed and replaced; furthermore, 1 participant was removed and replaced due to making too many errors (>50%) in the Go/No-Go task. However, after these initial replacements, 7 participants were further removed due to having many trials excluded (>50%) at the end of our EEG data processing pipeline. As these participants were not replaced, the total sample size of the analyzed data is 77 (mean age = 18.6; female = 52). Note that we originally aimed for n = 84 to have a large enough sample to appropriately assess the correlation between reaction times and ERD effects. Ultimately, this was based on a power analysis (via G*Power; Faul et al., 2007; Faul et al., 2009) showing that n = 84 leads to 80% power for detecting a medium correlation effect size (r = 0.3). Also note that the average sample size (per between-subjects cell) in previous Mu and Beta ERD studies is around n = 22.5 (based on the reviewed ERD studies described in the introduction). As such, the current study, with n = 77, is the largest study to date (that we are aware of) that

explores the effects of empathic pain observation on Mu and Beta ERD.

6.4.2 Apparatus and Stimuli

The experiment was programmed and presented using SuperLab v4.5 (Cedrus Corporation, San Pedro, CA, USA) and was run on a Lenovo P910 ThinkStation. We used short videos developed by Avenanti et al. (2010), and recently used by Riečanský et al. (2015) and Riečanský et al. (2020), depicting a Caucasian hand being stabbed by a needle or lightly touched by a Q-tip on the area of skin overlying the first dorsal interosseous (FDI). Each Video Type (Needle vs. Q-tip) consisted of three separate videos with the colour of the syringe and Q-tip handle varying. As per Avenanti et al. (2010), this was done to minimize effects of habituation. The signals used for the Go/No-Go task were orange and purple squares (counterbalanced). Participants responded with their right index finger using a Cedrus RB series Response Pad. EEG was recorded using a 60 channel Neuroscan Quik-Cap. Participants also completed the Interpersonal Reactivity Index (IRI; Faul et al., 2007; Faul et al., 2009) and Vicarious Pain Questionnaire (VPQ; Grice-Jackson et al., 2017).

6.4.3 Design

This experiment used a 2x2x2 repeated measures design, wherein Task Instructions (Active, Passive), Video Type (Needle, Q-tip), and Hemisphere (Left, Right) were the factors. The experiment was split into two blocks. In one block, participants were given the Active Task where they were told to press a button with their right index finger as fast as they could after seeing the Go Signal, but to inhibit their response if they saw the No-Go signal. In the other block, participants were given the Passive Task where they were told to simply relax their hands throughout the block. Needle and Q-tip videos were randomly shown throughout each block. Each block contained 120 trials, and of

these trials, 108 consisted of Go trials (90%). As such, participants completed a total of 240 trials throughout the experiment.

The trial by trial design began with participants observing a fixation cross (1500ms-2000ms, jittered). Next, a picture of the hand stimuli without any objects near it was presented (1800ms). This would then transition into the video stimuli with either a needle or Q-tip appearing to stab or touch the hand (1800ms). Lastly, the final frame of the video where the stab/touch was maximal was presented (1800ms). Immediately afterwards the Go/No-Go signal would appear (i.e., orange or purple square, counter-balanced). In the Active Task, the Go signal would appear until a response from the participant. In the Passive Task, the Go signal would last for 500ms. The No-Go signal, unless mistakenly prompted by the participant in the Active task, lasted for 500ms. See Figure 6.1.

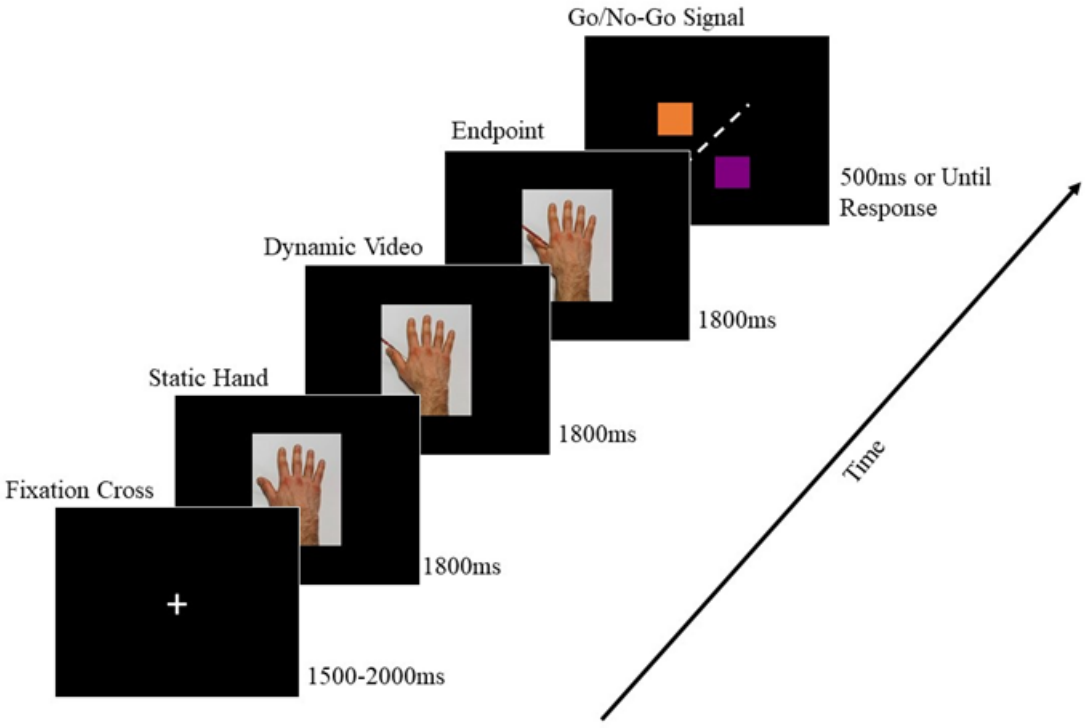

FIGURE 6.1: Visualization of a single trial.

6.4.4 EEG Acquisition and Processing

EEG was recorded using a 60 channel Neuroscan Quik-Cap. Impedance levels were below 15k before the start of the experiment. EEG during data collection was sampled at 1000Hz and online referenced to an extra electrode near Cz. After data collection was completed, the data was transferred to EEGLab (Delorme and Makeig, 2004). In EEGLab, the data was down-sampled to 250Hz and bandpass filtered between 0.1-40Hz. Bad channels were automatically detected and removed via the clean_rawdata plugin (ver. 2.1) and the data was re-referenced to the common average. Next, the data was epoched between -1s to 6s (no baseline correction) based on each condition (using the ERPLab plugin, ver. 7; Lopez-Calderon and Luck, 2014), and epochs that corresponded to bad behavioral trials (i.e., anticipatory responses ($<$ 150ms), missed trials ($>$ 1000ms)) were removed (less than 1.7% of all trials on average); epochs that contained extreme values ($\pm$ 500mV - this is usually due to major movements like stretching) were also removed (around 0.01%). Independent Component Analysis (ICA) was then run on each dataset using EEGLab's SOBI function (Second-Order Blind Identification; Sahonero-Alvarez and Calderón, 2017). The ICLabel plugin (ver. 1.2.4; Pion-Tonachini et al., 2019) was used to automatically classify and subsequently remove components classified as artifacts (i.e., sources coming from eye blinks, muscle movements, heartbeats, line noise, and channel noise). Afterwards, removed channels were interpolated and, as a final quality check, all epochs that contained $\pm$ 100mV waveforms were removed (around 5.5%) before final analysis.

Time-frequency decomposition was done via a custom Matlab script (based on instructions provided by Cohen, 2014). Power was analyzed from 1-30Hz in 0.25Hz increments. Morlet wavelets with a logarithmically increasing (relative to frequency) width (4-30) were applied for the time-frequency decomposition. A logarithmically increasing width was used to balance temporal and frequency resolutions (Cohen, 2014). Lastly, power values were normalized as a percentage increase or decrease relative to a baseline

period (-500ms). Based on previous work (i.e., Riečanský et al., 2015), we selected Mu (7-12Hz) and Beta (13-30Hz) bands, in left and right hemisphere regions of interests (ROIs; Left Hemisphere: C1, C3, CP1, FC1; Right Hemisphere: C2, C4, CP2, FC2), for analysis. Averaged power values were taken in the following time-windows: 200-1600ms (Static Hand), 2000-3400ms (Dynamic Video), and 3800-5200ms (Endpoint); note that the absent 200ms before and after each time-period of interest were removed to minimize carry-over between each time-period. See Figure 6.2.

6.4.5 Reaction Times, IRI, and the VPQ

Bad reaction time trials (i.e., anticipatory responses (< 150ms), missed trials (> 1000ms)) were removed (less than 1.7% of all trials on average) before final analysis. A simple pairwise t-test, between Needle Videos and Q-tip Videos, was conducted to test reaction time differences.

The IRI consists of four subscales: Personal Distress (PD), Perspective Taking (PT), Empathic Concern (EC), and Fantasy Scale (FS). PT reflects the tendency or ability to adopt the point of view of other people, FS reflects the tendency to transpose or identify strongly with fictional characters (in movies, plays, books, etc.), EC reflects the tendency to experience feelings of warmth, compassion and concern for others undergoing negative experiences, and lastly, PD reflects the amount of discomfort and anxiety that occurs as a result of observing the negative experiences of others. As such, we processed the IRI data accordingly (Davis, 1983; Davis, 1980). Note that 1 (out of 77) participant failed to answer all questions – this participant was not included in the correlational analysis involving the IRI.

The VPQ consists of 16 videos (no audio) of people experiencing physical pain in a variety of situations (e.g., injections, sports, etc.). Participants responded to several questions involving pain intensity, location, and pain descriptors after observing each video clip (for full details, see Grice-Jackson et al.'s (2017) supplementary data file).

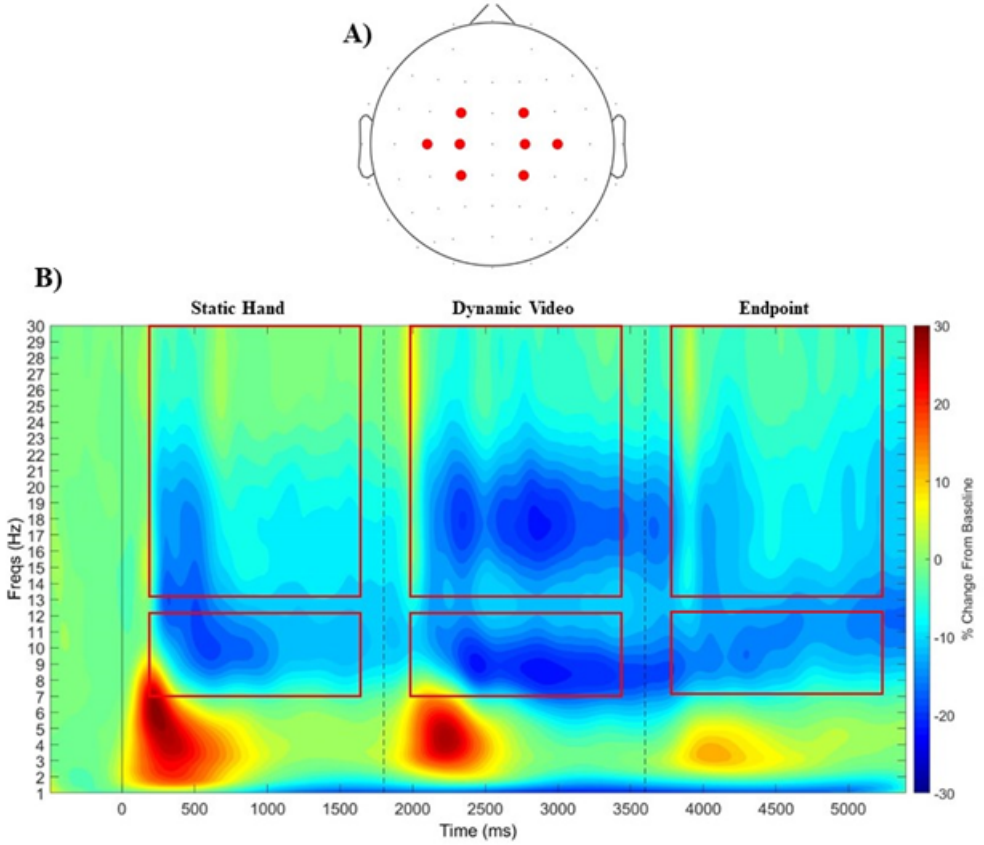

FIGURE 6.2: (A) The location of electrodes making up the left (C1, C3, FC1, CP1) and right (C2, C4, FC2, CP2) hemisphere regions of interest. (B) Event-Related Desynchronization / Synchronization (ERD/S) plot averaged across all participants, conditions, and electrodes. Dotted lines separate the three stimuli types (Static Hand, Dynamic Video, Endpoint). Red box indicates Mu (7-12Hz) and Beta (13-30Hz) frequency bands and the time-periods used for analysis.

Following Grice-Jackson et al. (2017), we performed a two-step cluster analysis, first involving a hierarchical cluster analysis using Ward's method (Ward, 1963), followed by a non-hierarchical k-means analysis with 50 iterations. The cluster centroids and number of clusters for the k-means analysis were guided by the hierarchical analysis. Following Grice-Jackson et al. (2017), and more recent work on the VPQ by Botan et al. (2018), we used the following variables in our clustering procedures:

1) Pain Intensity: The average intensity score for each video. 2) Localised-general: The total number of localised experiences minus the total number of non-localisable experiences. 3) Sensory-affective: The total number of sensory descriptors used minus the total number of affective descriptors used.

Note that the creators of the VPQ have made the video stimuli, along with explicit instructions on how to process the data, freely available on YouTube[1]. Further note that we opted to use data from all participants that completed the VPQ (n = 85), as larger datasets provide more accurate results. The end result of these processing steps led to three groups: Non-Responders (n = 52), Affective-General Responders (n = 10), and Sensory-Localized Responders (n = 15). Note that while the sample size is small in the latter two groups, they generally match the sample size originally used by Grice-Jackson et al. (2017; Non-Responders = 20, Affective-General Responders = 10, Sensory-Localized Responders = 10).

6.4.6 Procedure

Participants first read over a letter of information going over the tasks in the study. If they were comfortable with the procedures, they were asked to sign a consent form, and were fitted with the EEG cap. Afterward, the SuperLab program containing the experiment was played and the participant was presented with task instructions. Specifically, participants were told that each trial consisted of three events: a static picture

[1]see the following link: https://www.youtube.com/channel/UCT8goTgWGRsu14NjVaPCSGw/videos

of a hand, a dynamic video showing a needle or Q-tip stabbing or touching the hand (respectively), and a still picture of the final frame of the video. Furthermore, they were told that one of two possible coloured squares would appear immediately after the end of the last picture. In the Active Task block, participants were given a response pad and were instructed to press a button with their right index finger as fast as they could if they saw one colour (e.g., orange) and to withhold their response if they saw the other (e.g., purple) – the colours were counter-balanced across participants. In the Passive Task block, participants were instructed to simply relax their hands on the table in front of them (and were told that the coloured squares would simply disappear after a small amount of time). Task order was counterbalanced across participants. Both Active and Passive Task blocks contained Needle and Q-tip videos fully randomized. Participants were given self-paced breaks every 60 trials, and clear instructions were given at the half-way point when task instructions changed. At the end of the experiment, participants completed the VPQ and IRI.

6.4.7 Data Analysis Plan

As the current study's design closely matches Riečanský et al., 2015, we opted to follow their data analysis procedures. Specifically, we conducted 2x2x2 Within-Subjects ANOVAs across the three time-points of interest (Baseline Picture, Dynamic Video, and Endpoint) in both Mu and Beta frequency bands. Furthermore, to make sure that our stimuli are indeed eliciting desynchronization, we report one-sample t-tests against 0 of the averaged datasets (across all conditions); this also matches what was done in Riečanský et al., 2015. To explore if Mu and Beta ERD are functionally related to reaction times and/or are influenced by trait-levels of empathy, we will conduct a number of correlation between the reaction time effects/each subscale of the IRI with the ERD effects across each time-point and frequency band. Lastly, to see if the VPQ categories influence our results, we will add "VPQ Clusters" as a between-subjects factors (with

No Responder, Affective-General Responder, and Sensory-Localized Responder as categories) to the initial ANOVAs (this will be done in a separate section to explicitly divide our primarily analyses from our secondary).

6.5 Results

6.5.1 Mu ERD (7-12Hz)

Static Hand (200ms-1600ms)

The one-sample t-test against 0 was significant [$t(76) = 4.3$, $p < 0.0001$, $d = 0.48$; M = -8.19%, $SE = 1.9$]. The 2x2x2 within-subjects ANOVA yielded a significant main effect of Hemisphere [$F(1,76) = 17.1$, $p < 0.0001$, $\eta_p^2 = 0.18$], wherein there was larger ERD (more negative) in the Left Hemisphere [M = -9.64%, $SE = 1.93$] compared to the Right Hemisphere [M = -6.73%, $SE = 1.95$]. The results also showed a significant Hemisphere x Task Instructions interaction [$F(1,76) = 16.6$, $p = 0.0001$, $\eta_p^2 = 0.18$]. We conducted follow-up t-tests (Holms-Bonferroni corrected) to decompose this interaction. The results showed that in the Active Task, there was significantly larger ERD [$t(76) = 5.6$, $p < 0.0001$, $d = 0.64$] in the Left Hemisphere [M = -10.4%, $SE = 2.19$] compared to the Right Hemisphere [M = -4.67%, $SE = 2.26$]. No such difference was found in the Passive Task [$t(76) = 0.1$, $p > 0.9$; Left Hemisphere: M = -8.9%, $SE = 2.14$; Right Hemisphere: M = -8.79%, $SE = 2.01$]. All other effects were non-significant [all $p > 0.17$].

Dynamic Video (2000ms-3400ms)

The one-sample t-test against 0 was significant [$t(76) = 4.54$, $p < 0.0001$, $d = 0.52$; M = -12.1%, $SE = 2.66$]. The 2x2x2 within-subjects ANOVA yielded a significant main effect of Hemisphere [$F(1,76) = 11.6$, $p = 0.001$, $\eta_p^2 = 0.13$], wherein there was larger ERD in the Left Hemisphere [M = -13.9%, $SE = 2.72$] compared to the Right Hemisphere

[M = -10.25%, SE = 2.71]. The results also showed a significant Hemisphere x Task Instructions interaction [$F(1,76) = 16.3$, $p = 0.0001$, $\eta_p^2 = 0.18$]. We conducted follow-up t-tests (Holms-Bonferroni corrected) to decompose this interaction. The results showed that in the Active Task, there was significantly larger ERD [$t(76) = 4.7$, $p < 0.0001$, $d = 0.54$] in the Left Hemisphere [M = -16.2%, SE = 2.99] compared to the Right Hemisphere [M = -9.21%, SE = 3.22]. No such difference was found in the Passive Task [$t(76) = 0.29$, $p > 0.77$; Left Hemisphere: M = -11.6%, SE = 2.94; Right Hemisphere: M = -11.3%, SE = 2.63]. All other effects were non-significant [all $p > 0.39$].

Endpoint (3800ms-5200ms)

The one-sample t-test against 0 was significant [$t(76) = 4.45$, $p < 0.0001$, $d = 0.51$; M = -9.29%, SE = 2.1]. The 2x2x2 within-subjects ANOVA yielded a significant main effect of Hemisphere [$F(1,76) = 11.6$, $p < 0.001$, $\eta_p^2 = 0.25$], wherein there was larger ERD in the Left Hemisphere [M = -11.8%, SE = 2.14] compared to the Right Hemisphere [M = -6.77%, SE = 2.14]. The results also showed a significant Hemisphere x Task Instructions interaction [$F(1,76) = 31.9$, $p < 0.0001$, $\eta_p^2 = 0.29$]. We conducted follow-up t-tests (Holms-Bonferroni corrected) to decompose this interaction. The results showed that in the Active Task, there was significantly larger ERD [$t(76) = 6.7$, $p < 0.0001$, $d = 0.76$] in the Left Hemisphere [M = -14.8%, SE = 2.64] compared to the Right Hemisphere [M = -4.8%, SE = 2.75]. No such difference was found in the Passive Task [$t(76) = 0.1$, $p > 0.92$; Left Hemisphere: M = -8.85%, SE = 2.39; Right Hemisphere: M = -8.75%, SE = 2.15]. Crucially, the analysis also yielded a significant main effect of Video Type [$F(1,76) = 9.1$, $p = 0.0035$, $\eta_p^2 = 0.11$], wherein larger ERD occurred during the Needle Videos [M = -11.6%, SE = 2.25] compared to the Q-tip Videos [M = -6.98%, SE = 2.19]. All other effects were non-significant [all $p > 0.34$]. See Figure 6.2.

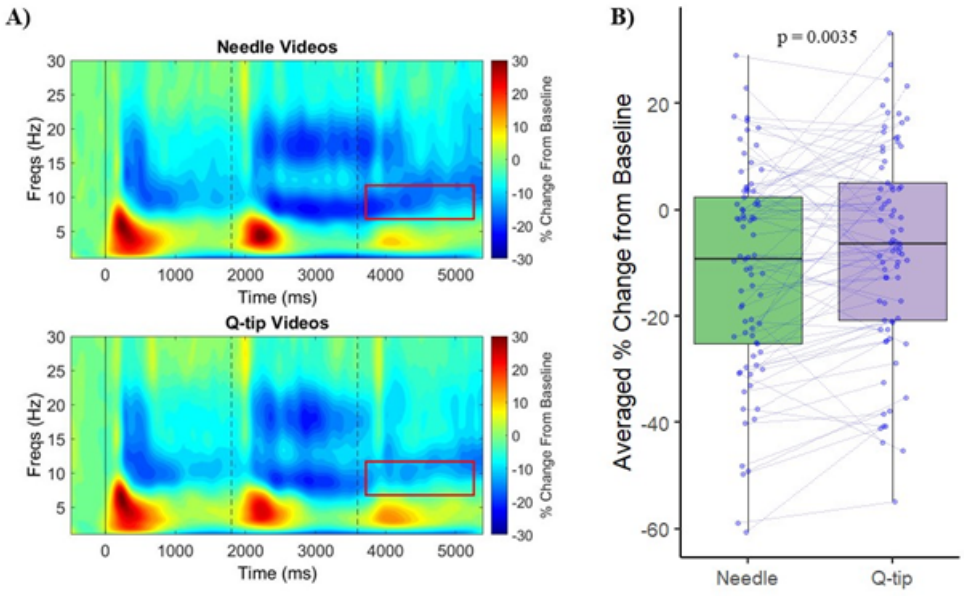

FIGURE 6.3: (A) Event-Related Desynchronization / Synchronization (ERD/S) plot averaged across all participants and split across Needle (top panel) and Q-tip (bottom panel) Video conditions (collapsed across Task Instructions and Hemisphere). Red box indicates the frequency (Mu) and time-period used for analysis. (B) Boxplot highlighting the significant main effect of Video Type (Needle vs. Q-tip) in the Mu (7-12Hz) band and Endpoint time-period of interest (see red box in Figure 3a). Blue dots represent individual averaged % change from baseline power; the blue dotted lines connect participant scores across conditions.

6.5.2 Beta ERD (13-30Hz)

Static Hand (200ms-1600ms)

The one-sample t-test against 0 was significant [$t(76) = 6.46$, $p < 0.0001$, $d = 0.74$; M = -4.5%, $SE = 0.7$]. The 2x2x2 within-subjects ANOVA yielded a significant main effect of Hemisphere [$F(1,76) = 6.94$, $p = 0.01$, $\eta_p^2 = 0.084$], wherein there was larger ERD in the Left Hemisphere [M = -5.11%, $SE = 0.79$] compared to the Right Hemisphere [M = -3.87%, $SE = 0.67$]. The results also showed a significant Hemisphere x Task Instructions interaction [$F(1,76) = 13.6$, $p = 0.0004$, $\eta_p^2 = 0.15$]. We conducted follow-up

t-tests (Holms-Bonferroni corrected) to decompose this interaction. The results showed that in the Active Task, there was significantly larger ERD [$t(76) = 4.67$, $p < 0.0001$, $d = 0.53$] in the Left Hemisphere [M = -6.58%, $SE = 0.92$] compared to the Right Hemisphere [M = -3.68%, $SE = 0.84$]. No such difference was found in the Passive Task [$t(76) = 0.6$, $p > 0.54$; Left Hemisphere: M = -3.65%, $SE = 0.95$; Right Hemisphere: M = -4.1%, $SE = 0.82$]. All other effects were non-significant [all $p > 0.25$].

Dynamic Video (2000ms-3400ms)

The one-sample t-test against 0 was significant [$t(76) = 8.41$, $p < 0.0001$, $d = 0.96$; M = -8.8%, $SE = 1.05$]. The 2x2x2 within-subjects ANOVA yielded a significant main effect of Hemisphere [$F(1,76) = 9.3$, $p = 0.003$, $\eta_p^2 = 0.11$], wherein there was larger ERD in the Left Hemisphere [M = -9.6%, $SE = 1.1$] compared to the Right Hemisphere [M = -8%, $SE = 1$]. A significant main effect of Task Instructions [$F(1,76) = 6.5$, $p = 0.013$, $\eta_p^2 = 0.08$], wherein there was larger ERD in during the Active Task [M = -10%, SE = 1.2] compared to the Passive Task [M = -7.5%, $SE = 1.1$]. The results also showed a significant Hemisphere x Task Instructions interaction [$F(1,76) = 20.3$, $p < 0.0001$, η_p^2 = 0.21]. We conducted follow-up t-tests (Holms-Bonferroni corrected) to decompose this interaction. The results showed that in the Active Task, there was significantly larger ERD [$t(76) = 5$, $p < 0.0001$, $d = 0.57$] in the Left Hemisphere [M = -12%, $SE = 1.3$] compared to the Right Hemisphere [M = -8.14%, $SE = 1.17$]. No such difference was found in the Passive Task [$t(76) = 1$, $p > 0.32$; Left Hemisphere: M = -7.2%, $SE = 1.2$; Right Hemisphere: M = -7.9%, $SE = 1.1$].

The analysis also yielded a significant Hemisphere x Video Type interaction [$F(1,76)$ = 5, $p = 0.028$, $\eta_p^2 = 0.06$]. We conducted follow-up t-tests (Holms-Bonferroni corrected) to decompose this interaction. The results showed that, in the Right Hemisphere, larger ERD was observed during the Needle Videos [M = -8.9%, $SE = 1.2$] compared to the Q-tip Videos [M = -7.1%, $SE = 1$]; however, this difference is not significant after

correction [$t(76) = 2.1$, $p = 0.078$]. In the Left Hemisphere, no difference was found between Needle Videos [M = -9.7%, $SE = 1.4$] and Q-tip Videos [M = -9.5%, $SE = 1.1$] before nor after correction [$t(76) = 0.13$, $p > 0.89$]. All other effects were non-significant [all $p > 0.09$].

Endpoint (3800ms-5200ms)

The one-sample t-test against 0 was significant [$t(76) = 7.1$, $p < 0.0001$, $d = 0.81$; M = -5.7%, $SE = 0.8$]. The 2x2x2 within-subjects ANOVA yielded a significant main effect of Hemisphere [$F(1,76) = 64.3$, $p < 0.0001$, $\eta_p^2 = 0.46$], wherein there was larger ERD in the Left Hemisphere [M = -7.8%, $SE = 0.9$] compared to the Right Hemisphere [M = -3.5%, $SE = 0.78$]. A significant main effect of Task Instructions [$F(1,76) = 12.4$, p = 0.0007, $\eta_p^2 = 0.14$], wherein there was larger ERD in during the Active Task [M = -7.5%, $SE = 1$] compared to the Passive Task [M = -3.8%, $SE = 0.9$]. The results also showed a significant Hemisphere x Task Instructions interaction [$F(1,76) = 42.1$, $p < 0.0001$, $\eta_p^2 = 0.36$]. We conducted follow-up t-tests (Holms-Bonferroni corrected) to decompose this interaction. The results showed that in the Active Task, there was significantly larger ERD [$t(76) = 9.3$ $p < 0.0001$, $d = 1.06$] in the Left Hemisphere [M = -11.5%, SE = 1.2] compared to the Right Hemisphere [M = -3.5%, $SE = 1.1$]. No such difference was found in the Passive Task [$t(76) = 0.9$, $p > 0.36$; Left Hemisphere: M = -4.2%, SE = 1; Right Hemisphere: M = -3.5%, $SE = 0.9$]. Crucially, the analysis also yielded a significant main effect of Video Type [$F(1,76) = 6.25$, $p = 0.015$, $\eta_p^2 = 0.076$], wherein larger ERD occurred during the Needle Videos [M = -6.8%, $SE = 0.98$] compared to the Q-tip Videos [M = -4.5%, $SE = 0.86$]. All other effects were non-significant [all $p >$ 0.07]. See Figure 6.4.

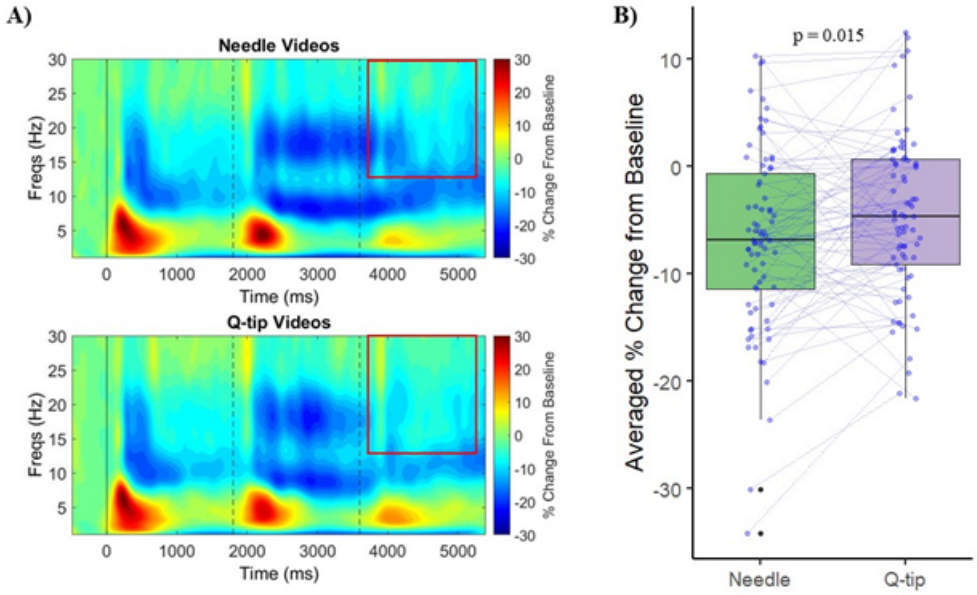

FIGURE 6.4: (A) Event-Related Desynchronization / Synchronization (ERD/S) plot averaged across all participants and split across Needle (top panel) and Q-tip (bottom panel) Video conditions (collapsed across Task Instructions and Hemisphere). Red box indicates the frequency (Beta) and time-period used for analysis. (B) Boxplot highlighting the significant main effect of Video Type (Needle vs. Q-tip) in the Beta (13-30Hz) band and Endpoint time-period of interest (see red box in Figure 3a). Blue dots represent individual averaged % change from baseline power; the blue dotted lines connect participant scores across conditions.

6.5.3 Reaction Times

We found a significant difference between Needle and Q-tip videos [$t(76) = 3.53$, $p = 0.0007$, $d = 0.4$] such that participants responded faster after observing the Needle videos [$M = 448$ms, $SE = 10.1$] compared to the Q-tip videos [$M = 456$ms, $SE = 9.95$]. To test if there is a relationship between the ERD and reaction time results, we correlated the magnitude of the reaction time effects (Q-tip – Needle) with the magnitude of the ERD effects (Needle – Q-tip). As the only significant effects of Video Type occurred as a main effect at the Endpoint (we skip the obtained Hemisphere x Video Type interaction effect as the follow-up t-test was not significant after correction), we conducted two correlations between the reaction time effect and the Mu and Beta ERD effect in this

time-period of interest. The results indicate non-significant correlations for both Mu [r = -0.018, $p > 0.87$] and Beta [$r = 0.023$, $p > 0.84$] bands[2].

6.5.4 Interpersonal Reactivity Index

Similar to the reaction time correlations, we opted to correlate each of the IRI subscales with the ERD effects of Video Type observed at the Endpoint. The analysis yielded a significant positive correlation between PD and Beta ERD, such that the higher the PD score, the larger the ERD effect became [$r = 0.23$, $p = 0.047$]. All other correlations were non-significant [all $p > 0.23$].

6.5.5 Vicarious Pain Questionnaire

The factor VPQ (consisting of three levels: Non-Responder, Affective-General Responder, and Sensory-Localized Responder) was added into to the main ANOVAs. As such, 2x2x2x3 mixed-design ANOVAs were conducted for each frequency band and across each time-period of interest (we include the Static Hand time-period for completeness). The results yielded a significant three-way interaction between Task Instructions, Video Type, and VPQ [$F(1,74) = 3.64$, $p = 0.03$, $\eta_p^2 = 0.09$], exclusively in the Beta frequency band and Endpoint time-period. All other effects involving the VPQ (across the other time-periods of interest and Mu) were non-significant [all $p > 0.08$].

To make sense of the three-way interaction, we conducted separate 2x2 ANOVAs for each VPQ condition. For the Non-Responders, the 2x2 ANOVA yielded a significant main effect of Task Instructions [$F(1,51) = 10.7$, $p = 0.0019$, $\eta_p^2 = 0.17$], wherein larger ERD was observed during the Active Task [M = -7.4%, $SE = 1.07$] compared to the Passive Task [M = -3.6%, $SE = 0.9$]; a significant main effect of Video Type [$F(1,51)$ = 10.2, $p = 0.0025$, $\eta_p^2 = 0.16$], wherein larger ERD was observed during the Needle

[2]Note that correlating the RT effect with ERD during the dynamic videos do not yield significant results either (Beta: $p > 0.94$; Mu: $p > 0.93$).

Videos [M = -7.1%, SE = 0.97] compared to the Q-tip Videos [M = -3.84%, SE = 0.95]; finally, the Task Instructions x Video Type interaction was non-significant [$p > 0.84$]. For the Affective-General Responders, the 2x2 ANOVA yielded no significant results [all $p > 0.29$]. Lastly, for the Sensory-Localized Responders, the 2x2 ANOVA yielded a significant Task Instructions x Video Type interaction [$F(1,14) = 17.9$, $p = 0.0008$, $\eta_p^2 = 0.56$]. We conducted follow-up t-tests (Holms-Bonferroni corrected) to decompose this interaction. The results did not yield any significant results between Needle and Q-tip Videos in either task [both $p > 0.07$ even before correction]. However, the pattern of means shows that, in the Passive Task, ERD was larger during the Needle Videos [M = 7.15%, SE = 2.9] compared to the Q-tip videos [M = -1.23%, SE = 2.4]; however, in the Active Task, ERD was smaller during the Needle Videos [M = -6.7%, SE = 2.9] compared to the Q-tip Videos [M = -10.1%, SE = 1.8].

6.6 Discussion

The aim of the current study was to explore if and how sensorimotor activity, indexed via Mu and Beta ERD, during pain observation is influenced by motor preparation. Our primary analyses do not show any evidence for such an influence. Instead, we found larger bilateral Mu and Beta ERD during pain observation vs. no pain, regardless if the participant was preparing to make an action or was passively observing the videos. This effect was also specific to when participants observed the Endpoint; that is, when the needle reached maximal needle penetration. While our analysis during the Dynamic Video seemed to reveal a lateralized effect of Video Type (for the Beta band), given that the follow-up analysis did not reach significance after correction, we hesitate to strongly interpret this finding. As such, the current results corroborate previous work showing that Mu and Beta ERD significantly increases during pain observation vs. no pain and extends this line of research by showing that motor preparation does not significantly influence this effect. The implications of this finding are interesting, as the main worry

regarding the generalizability of the experimental set up (of participants being instructed to remain still throughout the experiment) seems to be alleviated. Lastly, with the largest sample size (that we are aware of) collected to date, the current study provides support for the robustness of the Mu and Beta ERD effect during pain observation experiments.

Interestingly, we do not fully corroborate the temporal effects reported in Riečanský et al. (2015). Riečanský et al. (2015) report that they found larger Beta ERD (as a result of pain observation) during the Dynamic Video, but not the Endpoint; but found larger Mu ERD (as a result of pain observation) during the Endpoint, but not the Dynamic Video. There are a number of possible reasons that may explain this discrepancy. For example, while the current study used 1800ms videos (as this was the original video length reported in Avenanti et al., 2010), Riečanský et al. (2015) used 1500ms videos. It is possible, then, that the length of the videos may be influencing the results that have led to this discrepancy (also see Galang and Obhi, 2020 for an example of video length acting as a confound). Interestingly, Riečanský et al. (2020) report significant Mu and Beta ERD during pain observation (vs. no pain) in both Dynamic Video and Endpoint. In their study, participants observe the Needle/Q-tip videos on a screen placed above the participants right hand (via a box covering the participants hand). As such, it is possible that effects during the Dynamic Video may be dependent on how much self-other overlap a participant feels with the person's hand. Ultimately, more work will be needed to fully explore this issue. However, the fact that the Endpoint effect seems to elicit more robust effects across experiments using video stimuli corroborates previous experiments that have used picture stimuli, as these pictures are analogous to the Endpoint time-period.

Regarding reaction times, we replicated previous behavioural work and found that participants responded faster after pain observation compared to no pain (e.g., Riečanský et al., 2015; Riečanský et al., 2020). However, we did not find any significant correlations between the reaction time effect and the ERD effects. This was surprising as Mu and

Beta ERD are indicative of sensorimotor activity, and indeed, we found stronger Mu and Beta ERD in the Left Hemisphere during the Active Task compared to the Passive Task (suggesting that motor preparation was indeed occurring in the former compared to the latter). Thus, the lack of evidence of a correlation between reaction times and ERD for the Video Type effect suggests that they may operate independently from one another. Furthermore, as a motor response is at the end of a long chain of cognitive and physiological processes, it may also be possible that the two effects are just too far apart in the information processing chain for a salient relationship to arise. More work will be needed to fully elucidate the relationship between the neural correlates of pain observation and the behavioural output of such processes.

Regarding the IRI, we found a significant correlation between the Beta ERD effect (Needle – Q-tip) during the Endpoint and the Personal Distress (PD) subscale. This correlation suggests that participants who scored highest on trait-levels of personal distress also showed larger effects of pain observation (compared to no pain) on Beta ERD. Interestingly, as personal distress is a self-oriented response, this may suggest that Beta ERD may not be indexing empathic processing (an other-oriented response). Of course, given the weak statistical result in conjunction with the large number of correlations conducted, this result should be interpreted with caution. More importantly, the current study did not corroborate Cheng et al.'s (2008) finding that Mu ERD due to pain observation is correlated with the Perspective Taking (PT) subscale of the IRI. As such, future work is needed to further explore the external validity of using Mu and Beta ERD as an index of empathic processing.

Regarding the VPQ, we did not corroborate Grice-Jackson et al.'s (2017) original results. The current results show that VPQ does not interact with any of the experimental conditions in the Mu band. Interestingly, we did find that the VPQ interacted with Task Instructions and Video Type in the Beta Band Endpoint. This three-way interaction showed that the Non-Responders, contrary to their label, showed larger Beta

ERD during the Needle Videos compared to the Q-tip videos; the Affective-General Responders did not show any significant effects of Beta ERD; and lastly, the Sensory-Localized Responders showed an interaction between Task Instructions and Video Type, however, while the pattern of means suggest that motor preparation seemed to attenuate the ERD effect, the follow-up t-tests did not reach significance. As such, we hesitate to make any strong inferences from these results. Note, however, that while we did not corroborate Grice-Jackson et al.'s (2017) original results, there are a number of limitations with our implementation of the VPQ that may explain the discrepancy. First, Grice-Jackson et al. (2017) collected VPQ data from a much larger dataset ($n > 500$) before recruiting a smaller subset of those participants to participate in the EEG study. As such, Grice-Jackson et al. (2017) may have had more accurate VPQ clusters due to using a large dataset and the current study's less accurate results may be contributing to the discrepancy in results. Furthermore, as the VPQ was a secondary measure in this study, we opted to simply have participants complete it at the end of the EEG study. As such, observing videos of others getting hurt right before completing the VPQ may have also influenced participants answers. In sum, more work will be needed to corroborate the role of VPQ, as a measure of individual differences to pain observation, in sensorimotor activity.

In conclusion, the current study sought to test whether motor preparation influences sensorimotor activity, indexed via Mu and Beta ERD, during pain observation. The current results show no evidence of such an influence. Instead, we corroborate previous work showing that Mu/Beta ERD significantly increases during pain observation vs. no pain and do so using a large sample size (relative to previous work). We also report and discuss why sensorimotor activity does not seem to correlate with reaction times after pain observation and trait-levels of empathy and does not seem to interact with trait-levels of vicarious pain experiences. Overall, the current results show the robustness of sensorimotor activity during pain observation and highlights the need for more work in

connecting such activity to both explicit motor behaviours and empathic processing.

Chapter 7

General Discussion

7.1 Introduction

The aim of this dissertation was to answer two questions: what are the downstream behavioural effects of pain observation? And is there an association between sensorimotor resonance and such behavioural effects? Chapter 2-4 starts to answer the first question, while chapters 5 and 6 starts to answer the second. In this final chapter, I summarize the unique contributions and limitations of each data chapter (section 7.2), provide a general summary of the overall results (section 7.3), discuss the theoretical contributions of these findings and potential avenues for future research (section 7.4), discuss outstanding issues regarding arousal (section 7.5) and self-reported levels of empathy (section 7.6), and finally, conclude this dissertation (section 7.7).

7.2 Unique Contributions and Limitations of Each Chapter

7.2.1 Chapter 2

Given the conflicting/disparate results of Morrison et al. (2007b) and Morrison et al. (2007a) regarding the directional and temporal effects of pain observation on key presses, this study sought to test whether pain observation led to motor facilitation or inhibition. Furthermore, this study used stimuli previously used in TMS and EEG studies on

sensorimotor resonance (Avenanti et al., 2010; Riečanský et al., 2015), thus allowing for better comparisons across paradigms. The results of this study showed that observing others in pain led to a temporally extended and response general effect on overt motor behaviours (i.e., participants responded faster after pain observation, regardless of the temporal delay of the imperative cue and whether they responded with their right index finger or foot). As such, the results seem to be contrary to Morrison et al.'s (2007b) results, which suggests that key presses should be slower after pain observation, but also extends Morrison et al.'s (2007b) results by showing that motor facilitation after pain observations can occur 500ms after the stimuli offset; and lastly, the results show that such effects seem to not depend on the specific effector used to make a response, which may be interpreted as in contrast to TMS studies which report muscle-specific effects of pain observation on corticospinal activity (e.g., Avenanti et al., 2005).

There are three major limitations of this study. First, as participants were instructed to exclusively make key presses, we cannot directly compare these results to Morrison et al. (2007b) wherein participants responded with both key presses and releases. This limitation is addressed in chapter 4. Second, although these results seem to be in contrast with TMS studies (which would predict slower response times after pain observation due to the decrease in corticospinal activity during pain observation), the differences between methodologies make direct comparisons difficult. This limitation is addressed in chapter 5. Lastly, this study used a small sample size (n = 24) in a single experiment; as such, strong inferences are ill-advised until the results are corroborated with larger sample sizes. This issue is addressed in chapters 3, 4, and 6.

7.2.2 Chapter 3

The aim of chapter 3 was to both corroborate the results of chapter 2 and to extend this research by exploring how top-down and bottom-up processes modulate motor facilitation after pain observation. Across two experiments, motor facilitation after pain

observation was found. In experiment 2, it was shown that top-down processes, in the form of explicit instructions to empathize (vs. instructions to simply pay attention to the videos), accentuate motor facilitation after pain observation. No evidence for bottom-up processes, in the form of varying the perceived level of pain (i.e., needle pinprick vs. deep stab), influencing this effect was found. These results are important for a number of reasons. First, as chapter 2 presented a single experiment with n = 24, the experiments presented in this chapter provide much needed corroboration of the motor facilitation after pain observation effect. Second, the results that top-down, but not bottom-up, processes influence this effect provides further evidence of a dissociation between such behavioural results and previous TMS results on sensorimotor resonance (which instead suggests that it is bottom-up, rather than top-down, processes that influences sensorimotor activity during pain observation; Avenanti et al., 2006). Lastly, although we are theory-neutral on whether instructing participants to explicitly empathize actually led to an increase in empathy, these results nevertheless show that task instructions during these pain observation studies are potentially influential.

There are three major limitations in this study. First, as this study had participants exclusively use their right index finger, it is unclear how bottom-up and top-down factors would influence results using the right foot (or another effector). Second, as participants exclusively responded with a key press, these results cannot be directly compared to Morrison et al. (2007b); it would be interesting to see if/how responding with more adaptive behaviours (approach/withdraw movements) are modulated by the bottom-up/top-down manipulations. Lastly, as we are theory-neutral on whether instructing participants to explicitly empathize actually led to an increase in empathy, it is possible that alternative factors, such as an increase in attention and motivation, could be driving these results. Future work should include a third condition that uses task instructions to increase attention without mention of empathy.

7.2.3 Chapter 4

The aim of chapter 4 was to directly test whether the "natural mappings" of approach and withdrawal behaviours to key presses and releases influenced overt motor behaviours after pain observation (Morrison et al., 2007b). Across two experiments, the first using key presses and releases and the second using joystick forward and backwards movements as a proxy for approach and withdraw, there was no evidence to suggest that adaptive motor behaviours emerged as a result of pain observation. Instead, we found that participants generally responded faster after pain observation (vs. no pain), regardless of movement type nor the temporal delay of the imperative cue (no delay vs. 500ms). These results are in contrast to Morrison et al. (2007b), which suggested that, given a 500ms delay on the imperative cue, pain observation leads to slower key presses (approach) and faster key releases (withdraw). The current chapter also improves upon Morrison et al.'s (2007b) original design by both collecting larger sample sizes (n = 60 in each experiment vs. n = 23) and by running this study using a joystick (as key presses and release may be a poor proxy of approach and withdraw movements). As such, the current study strongly suggests that adaptive motor behaviours do not occur after pain observation.

A major limitation in comparing these results to Morrison et al., 2007b are the stimuli used. Whereas the experiments in this chapter used stimuli previously used in TMS experiments (e.g., Avenanti et al., 2005; Riečanský et al., 2015), Morrison et al. (2007b) created their own stimuli set. In particular, the pain videos specifically had the needle target the fingertips and included extra control videos involving a potato getting stabbed/touched by a needle/Q-tip. As such, it is possible that these differences are what led to the discrepant results between the experiments presented in this chapter and Morrison et al.'s (2007b) original findings.

7.2.4 Chapter 5

Whereas chapters 2, 3, and 4 sought to test the effects of pain observation on overt motor behaviours (and some potential modulators), chapter 5 instead explores how sensorimotor resonance measured via TMS is influenced by preparing such overt motor behaviours, and whether there is a correlation between the two. This is an important question, as the behavioural results, which finds motor facilitation after pain observation, do not seem to be consistent the TMS results, which finds a decrease in corticospinal activity during pain observation. In chapter 2, we hypothesized that this discrepancy could be explained by the task instructions used in each paradigm: whereas TMS studies instruct participants to remain still, behavioural studies necessarily have participants in a state of perpetual readiness. As such, the aim of chapter 5 was to directly test this hypothesis.

The results of this study were surprising. In the "passive" block, wherein participants were instructed to stay still, we expected to replicate previous TMS studies: a decrease in corticospinal activity during pain observation. In the "active" block, wherein participants were instructed to press a button at the end of each video stimuli, we expected the opposite effect: an increase in corticospinal activity during pain observation. Instead of finding these results, we found that there was a significant increase in corticospinal activity during pain observation regardless of block type. We also did not replicate our previous behavioural effects (motor facilitation after pain observation), although we speculate that this may have been due to the TMS, which can cause visible finger/muscle twitches, interfering with the button presses. As such, this chapter uniquely contributes to the sensorimotor resonance literature by finding conflicting results. Unfortunately, the lack of behavioural effects meant that we were unlikely to find a significant correlation between it and the TMS results (and indeed, we did not).

There are two major limitations in this experiment. First, as we did not collect

information on participant trait-levels of sense of control, self-other control, and embodiment (all factors that can contribute to observing a decrease in corticospinal activity during pain observation; De Coster et al., 2014; De Guzman et al., 2016; Bucchioni et al., 2016), it is unclear whether the surprising results of this experiment are due to one or more of these possibly confounding variables. Second, as we did not replicate the behavioural effects (i.e., motor facilitation after pain observation), we could not test whether the magnitude of the effect of sensorimotor resonance significantly correlated with the behavioural effect. This last issue is addressed in chapter 6.

7.2.5 Chapter 6

Chapter 6 extends chapter 5 by indexing sensorimotor resonance via EEG instead of TMS. In contrast to TMS studies, EEG studies on sensorimotor resonance show an increase in sensorimotor activity during pain observation (e.g., Cheng et al., 2008; Riečanský et al., 2015). These results better match the behavioural effect of motor facilitation after pain observation (as an increase in sensorimotor activity predicts faster reaction times), and as such, we expected a functional relationship between the two (via a significant correlation). Furthermore, as EEG does not cause finger/muscle twitches, we expected to replicate previous behavioural studies. Lastly, given that previous studies have shown that sensorimotor resonance occurs even when participants are instructed to remain still, we speculated that instructing participants to make overt behaviours would accentuate the sensorimotor resonance effect. The results of chapter 6 showed that pain observation leads to greater sensorimotor activity (measured via Mu and Beta desynchronization), and in the "active" block, participants responded faster after pain observation – thus, we successfully replicated the expected results in each paradigm. However, we did not find evidence for a significant correlation between the two effects, nor did the "passive" and "active" blocks modulate sensorimotor resonance. As such,

this chapter suggests that Mu/Beta desynchronization is robust to task instructions regarding motor preparation, and that the magnitude of such neural effects do not seem to correlate with the magnitude of the behavioural effects.

The major limitation of this experiment is the fact that EEG necessarily requires a number of signal processing choices (e.g. filters, artifact correction/rejection, frequency band limits, time-windows, etc.) that may increase analytical flexibility (e.g., Cohen, 2014; Luck and Gaspelin, 2017). Although we based our decisions on previous work in the field, it is nevertheless the case that future confirmatory research, ideally with pre-registered signal processing choices, will be needed to validate the results of this experiment. Furthermore, whereas TMS directly stimulates the motor cortex, the spatial resolution of EEG is comparatively low (e.g., Cohen, 2014). Indeed, just because a set of electrodes are placed on the scalp location corresponding to the central sulcus does not necessarily mean that the origins of the electrical signals measured by the electrodes are exclusively from the motor and somatosensory cortices (e.g., Luck, 2014). Although previous research seems to highly suggest that Mu and Beta desynchronization are indeed indexing sensorimotor processes, it is nevertheless the case that, compared to TMS research, EEG does not provide the same level of assurance without further analysis (e.g., via source localization).

7.3 Summary of Overall Results

In sum, this dissertation has revealed that pain observation affects overt motor behaviours by inducing motor facilitation in the form of faster reaction times. Such effects seem to be temporally extended (by at least 500ms after pain observation), effector-general (affecting both finger and foot responses), are influenced by top-down (i.e., instructions to explicitly empathize) but not bottom-up (i.e., the perceived level of pain) factors, and are not influenced by adaptive (approach/withdraw) behaviours. As such,

this dissertation extends previous research (i.e., Morrison et al., 2007a; Morrison et al., 2007b) by providing an in-depth exploration of the effects of pain observation on overt motor behaviour and exploring a number of modulating factors that do and do not influence such effects. The dissertation also found no evidence to suggest that motor facilitation after pain observation is significantly associated with sensorimotor activity during pain observation. This suggests that more work is needed to fully explicate the connection between sensorimotor processing of another's pain and motor facilitation after pain observation.

7.4 Theoretical Contributions and Future Directions

These results influence our theoretical understanding of empathy for pain by providing a strong answer to the question: "What are the downstream behavioural effects of pain observation?". The answer seems to be that pain observation robustly leads to overt motor facilitation in the form of faster reaction times. Unfortunately, as we did not find that adaptive approach-withdraw behaviours influenced motor facilitation, the functional significance of such motor facilitation remains to be seen; however, we can draw on work by Han et al. (2017) to perhaps fill this gap. Han et al. (2017) provide evidence to suggest that a continuous keypress may be functionally related to self-distress relief via attenuating activity in the secondary somatosensory cortex during pain observation. As such, it is possible that motor facilitation after pain observation may provide a similar function. Of course, Han et al. (2017) had participants continuously press a key, measured response force (rather than reaction times), and did so during, rather than after, pain observation. As such, future research will be needed to see if reaction times after pain observation also provide self-distress relief. For example, participants could rate their self-distress levels after each video stimuli, while half of the participants are tasked to also press a key immediately after the stimuli and the other half to simply observe the videos. If reaction times after pain observation are indeed functionally

related to self-distress relief, then I expect that the former group to significantly report less self-distress due to the stimuli compared to the latter.

Of course, the results of chapters 5 and 6 seem to suggest that sensorimotor activity is not associated with motor facilitation after pain observation (via reaction times). However, note that TMS specifically targets the primary motor cortex and it is unclear where the exact source of Mu rhythms are occurring; as such, it is possible that such measures were not spatially sensitive enough to detect activity in the relevant regions (i.e., secondary somatosensory cortex) compared to fMRI. It is also possible that a continuous keypress during pain observation would have a larger influence on these neurophysiological measures compared to reaction times after pain observation. Unfortunately, it would be quite difficult to measure both MEPs and electrical signals if the participant is continuously pressing a button (as motor artifacts would inevitably be present in the data). However, at least for EEG, methods such ICA may be able to separate such motor artifacts from neural signals given the continuous nature of the action. As such, future research will be needed to address this issue.

Another possible avenue for future research is the use of context to explore the functional significance of overt motor behaviours after pain observation. A major limitation of this dissertation is that the overt motor behaviours were conducted for an arbitrary reason (e.g., "press the key when you see an orange square"). Note that the key press itself is a very simplistic movement and does not capture the full range of possible behaviours a person may do after observing another in pain; however, such limitations are necessary to maintain experimental control – the more complex the behaviour, the more variance that will occur across participants. Nevertheless, it is possible to manipulate the purpose of simple actions via task instructions and stimuli. For example, one could have participants observe only half of a video depicting a needle stabbing a hand before a coloured square appeared; they are then told that one colour indicates that the rest of the video (of the needle stabbing the hand) will play, while the other colour indicates

that the needle will not stab the hand (via reversing the video). In the former case, pressing the key after seeing the square will lead to observing the other in more pain, while in another it leads to removing the noxious stimuli. It is possible that motor facilitation will only occur when the keypress outcome is prosocial (removing the noxious stimuli). If so, then this may provide some evidence that motor facilitation after pain observation may be functionally related to preparing the observer to help the person in pain. The lack of significant correlations between sensorimotor resonance and overt motor behaviours may also be explained by the arbitrariness of the actions – future research will be needed to address these issues.

7.5 Empathy for Pain or Arousal?

One of the main issues that has consistently come up during my studies is whether motor facilitation after pain observation is due to empathy for pain or arousal. High states of arousal can lead to faster reaction times (e.g., Martinie et al., 2010), and Avenanti et al. (2010) has shown that observing the video stimuli used throughout this dissertation can lead to an increase in autonomic activity (i.e., heart rate, skin conductance) indicative of increased arousal. As such, it is possible that motor facilitation after pain observation is merely due to a heightened state of arousal caused by observing another in pain. However, note that arousal does not always lead to faster reaction times. For example, early work by Nishisato (1966) found that reaction times were slower when participants were in a state of high arousal (measured via skin conductance). More recent work by Feng et al. (2012) showed that neither arousal nor valence influenced reaction times in a forced-choice paradigm.

As discussed in chapters 2 and 3, an apt comparison to work done in this dissertation is with that of De Houwer and Tibboel (2010), wherein they had participants complete a

Go/No-Go task interleaved between presentations of pictures from the International Affective Picture System (IAPS; Lang et al., 2008). The IAPS contains standardized sets of picture stimuli rated on both valence and arousal. De Houwer and Tibboel (2010) found that participants responded slower to the Go signal after observing a highly arousing image (both positively and negatively valenced). They interpreted these results by suggesting that high arousal stimuli command more attentional resources, and thus, detract attentional resources needed to process the subsequent imperative cue. Similar results were reported Verbruggen and De Houwer (2007), although participants completed a stop-signal task instead of a Go/No-Go task. While there is the notable difference between using picture vs. video stimuli, these results nevertheless suggest that pain observation should lead to slower reaction times. The fact that this dissertation consistently reports faster reaction times after pain observation suggests that arousal cannot fully account for such results.

Of course, this fact alone does not mean that motor facilitation after pain observation is the result of empathy for pain. As outlined in the introduction, empathy has two necessary (and together sufficient) requirements: affective state matching and self-other distinction (Preston and De Waal, 2002; de Vignemont and Singer, 2006; Bird and Viding, 2014). Affective state matching is presumed to occur through perception-action coupling, such that observing another's state activates the same representations in the observer (Preston and De Waal, 2002; De Waal and Preston, 2017). In practice, this often leads to researchers looking for overlapping neural activation between the first-hand experience of pain and empathy for pain (e.g., Lamm et al., 2011).

On one hand, as we are using stimuli that have been used in previous neurophysiological research (e.g., Avenanti et al., 2010; Riečanský et al., 2015), it could be inferred that such overlapping neural activations are occurring and thus the affective state matching criteria has been fulfilled. On the other hand, and as discussed in chapter 3, if affective state matching arises as a result of overlapping neural representations/activations, then

we ought to find similar behavioural effects between the first-hand experience of pain and pain observation. A pertinent study was conducted by Perini et al. (2013) where they had participants respond to an imperative cue after pain vs. no pain stimulation and found that painful stimulation led to faster reaction times, thus matching motor facilitation after pain observation. However, direct comparisons cannot be made as Perini et al. (2013) had participants use the opposite hand (to the one receiving the painful situation) to respond. Another study by May et al. (2017) had participants respond with the same hand receiving the stimulation; however, such responses were made to the stimulation rather than after and faster reaction times were observed as a function of stimulation intensity rather than pain vs. no pain. As such, more research will be needed to fully explore this topic.

Regarding the self-other distinction criteria, although it is not explicitly stated, most empathy for pain studies assume this occurs as a result of task instructions to focus and pay attention to the emotional state of the person(s) in the picture/video stimuli. In this regard, behavioural studies on pain observation fulfill this criterion. Furthermore, as the results chapter 3 suggest that explicitly instructing participants to empathize accentuates motor facilitation after pain observation (compared to instructing them to simply focus and pay attention), it is possible that self-other distinction was high in this particular experiment.

In sum, there is some evidence to suggest that motor facilitation after pain observation is caused by empathy for pain; however, more work will be needed to establish that affective state matching is indeed occurring during pain observation. Of course, whether reaction times are measuring true empathy is difficult to discern. Indeed, Singer and Lamm (2009) have noted that "[...] *there are almost as many definitions of empathy as there are researchers in the field*" (pg. 82). This dissertation has also focused on a specific subset of empathy related to sensorimotor activity and says nothing about the other components of empathy (e.g., cognitive empathy). As such, more theoretical work

is needed to fully explicate what does and does not count as empathy, and where the reaction time effects reported in this dissertation fit in this framework.

7.6 Self-Reported Empathy

Another way to validate these effects as measuring empathy is to correlate them with trait measures of empathy. However, a prevalent finding throughout this dissertation is the lack of significant correlations between self-reported levels of empathy and motor facilitation after pain observation. The most common measure used in these studies is the Interpersonal Reactivity Index (IRI; Davis, Davis, 1983; Davis, 1980). The IRI contains four subscales: Perspective Taking (PT), Fantasy Scale (FS), Empathic Concern (EC), and Personal Distress (PD). PT reflects the tendency or ability to adopt the point of view of other people, FS reflects the tendency to transpose or identify strongly with fictional characters (in movies, plays, books, etc.), EC reflects the tendency to experience feelings of warmth, compassion and concern for others undergoing negative experiences, and lastly, PD reflects the amount of discomfort and anxiety that occurs as a result of observing the negative experiences of others. Note that PD is not considered a measure of empathy as it is self-focused; whereas FS is a combination of PT and EC specifically applied to fictional characters. Importantly, correlations with such subscales are sometimes used as a form of construct validity for neurophysiological measures of empathy for pain. For example, Avenanti et al. (2009a) found that sensorimotor resonance, measured via TMS, is positively correlated with PT and negatively correlated with PD. This suggests that larger decreases in corticospinal activity during pain observation (relative to no pain) correlated with higher perspective taking scores, but smaller personal distress scores. Cheng et al. (2008) found that Mu desynchronization positively correlated with PT, such that stronger somatosensory activity during pain observation (related to no pain) correlated with higher perspective taking scores. As such, it may be worrisome that overt motor behaviours after pain observation do not show such correlations.

One possible reason for this discrepancy is provided by Hedge et al. (2018), who have recently provided strong evidence to suggest that robust cognitive tasks, including Go/No-Go tasks, may not be suitable for tracking individual differences. This is due to the fact that such tasks are designed to limit between-subjects variance, whereas self-report inventories emphasize such variance. This subsequently leads to low internal reliability for cognitive tasks, which in turn leads to a higher chance of not finding (nor replicating) significant correlations. As such, given the use of the Go/No-Go task, it is possible that the lack of significant correlations reported in this dissertation is due to this fact; and as TMS and EEG studies often do not have their participants complete a cognitive task during the session, it is possible that between-subjects variance is thus emphasized (or at least not minimized) during these studies. This then makes them more suitable for correlations with self-report scales. However, note that there are some inconsistencies in the literature. For example, contrary to Avenanti et al. (2009a), Fitzgibbon et al. (2012) and Bucchioni et al. (2016) report no significant correlations between sensorimotor resonance measured via TMS and self-reported empathy; and contrary to Cheng et al. (2008), Yang et al. (2009) found that Mu desynchronization correlated with PD (at least in male participants) rather than with PT. Note that this reasoning may also explain the lack of significant correlation between the reaction time effect and the Mu/Beta effects reported in chapter 6. As a last point, Hedge et al. (2018) notwithstanding, it is possible that the IRI subscales are simply not capturing the same constructs as those indexed by reaction times after pain observation. Perhaps the use of more context specific scales, such as the Empathy for Pain scale (Giummarra et al., 2015), better captures these constructs. More work will be needed to fully elucidate this issue.

7.7 Conclusion

This dissertation investigated the downstream behavioural effects of empathic pain observation, as well its potential connection to sensorimotor resonance. The primary findings are that pain observation leads to motor facilitation in the form of faster reaction times, and such motor facilitation does not seem to be related to purported measures of sensorimotor resonance (assessed via TMS and EEG) during pain observation. I discussed a number of limitations and outstanding issues, as well as suggesting future avenues of research. Overall, this dissertation furthers our understanding of the downstream overt motor consequences of pain observation and the potential relationship (or lack thereof) of these overt consequences with the more covert phenomenon of sensorimotor resonance. A complete explanation of how covert sensorimotor activity associated with pain observation is related to overt motor responding remains elusive, and in this regard, this thesis opens up many possibilities for future work.

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