Can't touch this: the first-person perspective provides privileged access to predictions of sensory action outcomes.

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Abstract

Previous studies have shown that viewing others in pain activates cortical somatosensory processing areas and facilitates the detection of tactile targets. It has been suggested that such shared representations have evolved to enable us to better understand the actions and intentions of others. If this is the case, the effects of observing others in pain should be obtained from a range of viewing perspectives. Therefore, the current study examined the behavioural effects of observed grasps of painful and non-painful objects from both a 1st and 3rd person perspective. Participants were faster to detect a tactile target delivered to their own hand in the 1st person perspective when viewing painful grasping actions, compared to all non-painful actions. However, this effect was not revealed in the 3rd person perspective. The combination of action and object information to predict the painful consequences of another person's actions when viewed from the 1st person perspective, but not the 3rd person perspective, argues against a mechanism ostensibly evolved to understand the actions of others.

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Can't touch this: the first-person perspective provides privileged access to predictions of sensory action outcomes.

Viewing others perform actions (e.g., Oosterhof, Wiggett, Diedrichsen, Tipper & Downing 2010; Rizzolatti & Craighero, 2004), display emotions (Wicker, Keysers, Plailly, Royet, Gallese & Rizzolatti, 2003), encounter touch (Keysers, Wicker, Gazzola, Anton, Fogassi & Gallese, 2004; Bufalari, Aprile, Avenanti, Di Russo, & Aglioti, 2007) and pain (Morrison, et al., 2007; Singer, Seymour, O'Doherty, Kaube, Dolan & Frith, 2004) elicits activation of neuronal ensembles that are similarly recruited when we directly experience these phenomena. A prominent view is that these 'shared representations' are a product of specialized brain mechanisms that give people direct insights into the internal states of others (e.g., Ramachandran, 2000; Ramachandran & Oberman, 2008; Schütz-Bosbach, Mancini, Aglioti, & Haggard, 2006). On this view, shared representations have evolved as adaptations to the requirement of having to understand the behavior of conspecifics, and confer substantial adaptive advantages: they help people to empathise with one another, to coordinate and predict future actions, and to detect deception. Consistent with such a primarily social role, a large number of mirror neurons are viewpoint independent or respond selectively to actions from a 3rd person perspective (Caggiano et al., 2011; Oosterhof, Tipper, & Downing, 2012), and there is increasing evidence that disrupting shared representation also disrupts social understanding (for review, see Avenanti, Candidi, & Urgesi, 2013).

Recently, however, the view that shared representations evolved specifically to facilitate social understanding has been challenged (cf. Heyes, 2010; Brass & Heyes, 2005; Keysers & Perrett, 2004). These theories do not deny that shared representations are computed in a wide range of circumstances or that they play a crucial role in action

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understanding and empathy. However, instead of emerging from specifically evolved brain systems for social understanding, shared representations are seen as (very useful) by-products of the processes that monitor and control the individual’s own actions (e.g., Brass & Heyes, 2005; Heyes, 2010; Keysers & Perrett, 2004; Gallese, 2001). Prediction processes – and the internal models they rely on – have taken centre stage in such accounts. Humans constantly predict how their bodies will affect the environment, and how the environment will affect them (e.g., Friston, 2010; Schütz-Bosbach & Prinz, 2007). These predictions allow them to take evasive action, make course corrections, or stop actions altogether if negative outcomes are expected. They emerge from sophisticated processes combining multiple sources of information. During reaching, for example, actors combine information about their action with the internal model of the goal object – its anticipated weight, softness and texture – to predict the specific consequences of grasping it, such that grips can be adjusted and future actions can be planned before contact is made (for a review, Johansson & Flanagan, 2009).

We and others have argued that shared representations could emerge naturally from such prediction mechanisms (e.g., Morrison, Fenton-Adams, Tipper, & Bach, 2013; Bach, Bayliss, & Tipper, 2012; Kilner, Friston, & Frith, 2007; Miall, 2003; Gallese, 2001). Because the visual input to these mechanisms is very similar during both action and observation, the same integration processes can take place, and yield the same predictions of action outcomes. A recent study (Morrison, et al., 2013) provided initial evidence for this idea. Participants watched hands either grasp or withdraw from painful and non-painful objects, and judged the appropriateness of these actions. We tested whether observers’ tactile processing systems would represent the painful sensory consequences associated with grasping the painful object. Importantly, no direct cues to pain were shown, such as skin damage or negative emotional expressions. Any sensory expectation of pain could therefore not be directly

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extracted from the stimulus, but – similar to action execution – had to be predicted by combining action information (whether it involves hand-object contact) with the internal model of the goal object (whether it is painful to touch). Indeed, we found that observers' somatosensory cortices showed higher activations for painful grasps than in any other hand-object interaction that did not cause pain, suggesting that participants indeed made such predictions. Moreover, subsequent psychophysical experiments revealed that seeing painful grasps also increased participants' readiness to detect tactile stimulation on their own fingers, but not auditory stimulation. The lack of effect with auditory stimuli ruled out more general attention/arousal related explanations of the effects, and revealed that the predictions of sensory action outcomes specifically affected sensory-tactile representation systems.

These findings show that people make sophisticated predictions about the outcome of others' actions, but it remains an open issue whether these predictions emerge from processes evolved to enable social understanding or to enable the prediction of consequences for the self. The present study tests these alternative hypotheses, following a logic introduced by Oberman and Ramachandran (2008; for related approaches, see Gallese, 2001; Schütz-Bosbach, et al., 2006). It rests on the notion that a mechanism that has evolved for monitoring one's own actions should be driven most directly by visual input that matches the 1st person view one has of one's own actions. The sensory consequences of others actions should therefore be derived effectively when seen from this 1st person perspective, but less so when they are seen from a 3rd person view, which captures the typical viewpoint when watching the actions of others. The opposite pattern is predicted if these mechanisms are specialized for social understanding (cf. Oberman & Ramachandran, 2008). That is, simulation of the sensory consequences of an action should be activated when observing the actions of another person which are typically viewed from the 3rd person perspective, rather than one's own actions typically viewed from a 1st person perspective. Such a specialisation for the actions of others has indeed been demonstrated for the case of automatic imitation. Motor responses during action observation are stronger if the action is attributed to another person, rather than to oneself (Schütz-Bosbach, et al., 2006).

To test these predictions, we adapted the psychophysical paradigm of Morrison et al. (2013). As before, participants watched hands grasp or not grasp objects that could be painful or non-painful and, at the same time, pressed a button whenever they felt supraliminal tactile stimulation on their own fingers. The readiness to detect such stimulation – measured by response times – when participants viewed grasps of painful objects (relative to grasps of neutral objects, or misses of either type) served as a measure of the extent to which participants inferred the sensory-tactile consequences of these actions.

Two important changes were made to the original design. First, in the original study participants judged whether the actions were appropriate to the object (e.g., grasps were appropriate for neutral objects but not painful ones, and vice versa for withdrawals), a task which by itself encouraged deriving the sensory consequences of the actions. To test natural biases in prediction systems it is crucial to eliminate such top-down task influences and to tap into more automatic modes of processing. Thus, after participants were familiarized with the painful and non-painful objects, they merely reported whether the hand made contact with the object or not; whether this contact would cause pain was not task relevant.

Second, in the original study, participants saw the actions from the side. To be able to manipulate the closeness of the visual input to either one's own or other people's actions, the actions were now presented from a bird's eye perspective. This allows us to generate 1st person and 3rd person views by simply mirroring the displays along the horizontal axis, but showing otherwise identical stimuli. Thus, in the *1st person perspective* condition, the stimuli were rotated such that they matched the input one receives from one's own actions: during the reach, the hand moved away from the participant towards an object, while the arm pointed backwards to the approximate location of the participants' body. In contrast, in the *3rd person perspective* condition, the stimuli were rotated to match the view one has of the action of another person. During the reach, the hand moved towards an object and the participant, while the arm pointed forwards, away from the participant's body.

This paradigm allowed us to test, first, whether observers' tactile representation systems would predict the sensory consequences of grasping painful objects even when the nature of the object was irrelevant to the task. If this is the case, tactile stimulation should again be detected more quickly when viewing painful grasps, compared to any other type of hand-object interaction that does not cause pain (grasps of neutral objects, or misses of either type of object). Second, it allows us to test how viewing perspective affects these automatic predictions. If sensory predictions emerge from mechanisms for representing one's own actions, these effects should be stronger for actions seen from the 1st person compared to a 3rd person perspective. In contrast, if they emerge from a dedicated system for social understanding, any effects should be stronger in the 3rd than the 1st person perspective.

Note that prior studies have indeed demonstrated impressive effects of 3rd person information, such that the observer's internal state was affected by what another person attempted to ignore (Frischen et al., 2009), attempted to avoid (Griffiths & Tipper, 2009), or by what they could see (Samson et al. 2010). However, the internal states of interest were typically (1) directly discernible from the visual stimulation, (2) did not require internal inference or combination of sources of information, or (3) were observed in tasks where representing the others' perspective was encouraged by task or stimuli. Moreover, (4) none of these studies implemented a 1st person control condition. Ours is the first study to dissociate predictive and social understanding views of shared representations, where the outcome of more sophisticated prediction processes can be compared across perspectives.

Method

Participants. 48 participants (14 male, 3 left-handed) were recruited through the Bangor University, School of Psychology, participation panel. All were aged 18 years or over (*M* = 20.23, *SD* = 3.14), had normal or corrected-to-normal vision, and were first language English speakers. They received course credits to compensate them for their time. The procedures were approved by the School of Psychology Ethics Committee, Bangor University, Wales.

Apparatus. Visual and tactile stimuli were presented using Presentation (www.neurobs.com) on a 3.2 Ghz Pentium computer running Windows XP. The tactile stimulator, an Oticon BC462 bone conductor, was attached to the tip of the participant's right index finger with adjustable tape. The stimulation was a 200 Hz sine wave, overlaid with white noise, lasting 50 ms. The first and last 10ms were faded in and out to prevent sharp transients. Participants wore earplugs and ear protectors to prevent them from hearing the stimulation device.

Stimuli. Participants viewed two-frame action sequences. Each sequence was shot from a birds-eye perspective and showed a hand interacting with one of 7 painful and 7 non-painful objects (Figure 1a). The first frame always showed a hand in a neutral position near an object (for 750 ms). The second frame (500 ms.) showed the same hand either grasp or miss the object. The two frames followed each other without a gap, creating the impression of apparent motion (Figure 1b).

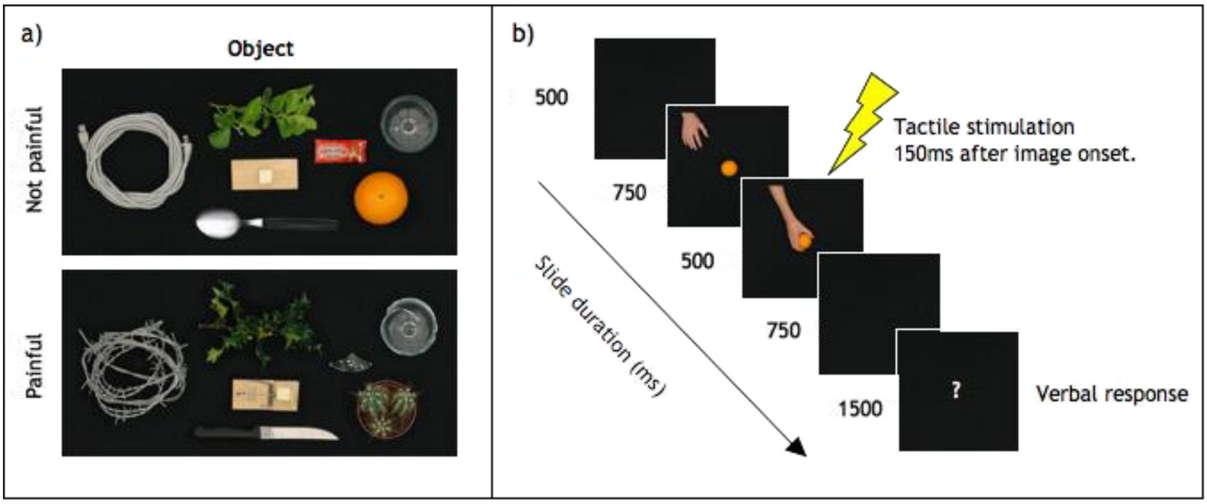

Figure 1. a) Examples of object stimuli. Non-painful objects included a cable, plant, cheese on a wooden board, a spoon, a tomato sauce sachet, a wine glass and an orange. Painful objects included barbed wire, holly, a loaded mousetrap, a serrated sharp knife, a shard of glass, a broken wine glass and a cactus. b) Schematic of tactile detection task (4000 ms total trial duration). Tactile stimulation (50ms duration) occurred 150ms after the onset of the frame where the hand interacted with the object. The delayed verbal response occurred during the final frame of the trial sequence, when the question mark was on screen.

Each sequence could be shown in the 1st person or the 3rd person perspective (Figure 2). The same photographs of hands and objects were used for each perspective by flipping and rotating the images. In the *1st person perspective* condition, the stimuli were rotated such that they matched the input one receives from one’s own actions: during the reach, the hand moved away from the participant towards an object. In the *3rd person perspective* condition, the stimuli were rotated to match the view one has of the action of another person. During the reach, the hand moved towards an object and the participant.

In the 3rd person perspective, as a between subjects factor, participants either viewed an anatomical match of the 1st person perspective hand (i.e. a right hand in the 1st person perspective and a right hand in the 3rd person perspective) or a mirror image of the 1st person perspective hand (i.e. a right hand in the 1st person perspective and a left hand in the 3rd person perspective) (see Figure 2). This factor of no interest was included to account for

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possible differential effects of specular and mirror image forms or 3rd person perspective stimuli (e.g., Bertenthal, Longo, & Kosobud, 2006).

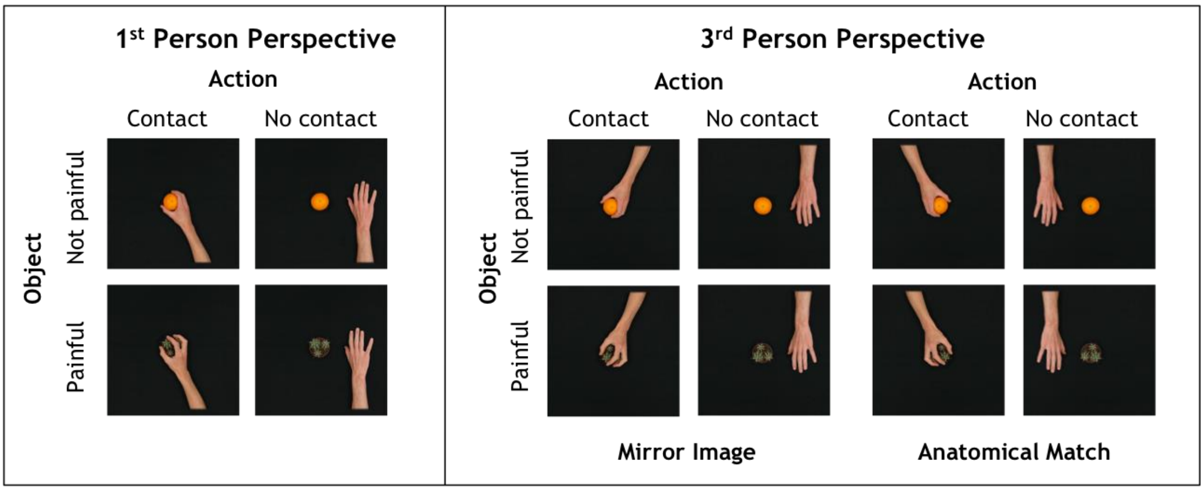

Figure 2. Example of experimental conditions. *Within participants:* viewpoint (1st person perspective/3rd person perspective), action (contact/no contact) and object (painful/not painful). *Between participants*: 3rd person mapping (mirror image/anatomical match).

Design and Procedure. To familiarize participants with the painfulness of the objects, they first completed a computer-based 28-item rating scale questionnaire (see Morrison et al., 2013). Using a 5-point Likert scale (1 = *not at all* to 5 = *very much*), participants rated each of the 14 objects they would see during the experiment on how painful they imagined it would be to grasp the object, and to what degree they judged this from their own experience. To ensure participants would recognize the stimuli, a side view of the object (see Supplementary Figure 1) was displayed for 2000 ms. The object was then presented in the birds-eye view for painfulness ratings, which was the form in which it was seen throughout the rest of the experiment.

On completion of the rating scale, participants inserted the earplugs and wore ear protectors. Participants attached the stimulation device to their right index finger. The stimulation device was switched on to familiarise the participant with the tactile stimulation and the tactile detection task. Participants were requested to press the spacebar on the keyboard with their left hand as quickly as possible whenever they felt the tactile stimulation. The tactile target was the same as during the experiment proper.

When the experimenter was confident the participant could perform the task correctly, participants completed 16 practise trials that were randomly selected from the main experimental trials. Participants viewed two frame sequences of a hand either approach and grasp, or miss, painful and non-painful objects, from a 1st person perspective and 3rd person perspective (see Figure 1 and 2). Tactile stimulation occurred 150 ms after the onset of the second frame (where the hand performed the action) on 80% of the trials. At the end of each trial, regardless of whether there was tactile stimulation or not, participants had to make a verbal response about whether the action involved “contact” or “no contact”.

The experiment proper consisted of 280 trials in total and was subdivided into four blocks. Trials were equally distributed over the eight different conditions (object painful/non-painful x contact/no contact x perspective), with 35 trials in each condition, 27 of which were trials with tactile stimulation. Each of these four blocks was preceded by a shorter block of 16 trials that served to remind participants about the painfulness of the objects. In these blocks, participants saw the same actions and performed the same task but were asked whether the object they had seen was potentially “painful” or “not painful”.

Results

Three additional participants were excluded for not performing the task correctly. One participant did not report whether the hand made contact but reported object painfulness instead. The other two did not respond in a speeded manner to the tactile stimulations (mean RTs > 1500 ms). Pre-emptive detections (<100ms) and reaction times greater than 1500ms were removed from the data (0.49%). The data for reaction times (Figure 3), hits, and false alarms (Figure 4) were entered into separate 2 x 2 x 2 repeated measures ANOVA with the factors viewpoint ($1^{st}/3^{rd}$ person perspective), action (contact/no contact) and object (painful/not painful) and the between groups factor of 3^{rd} person mapping (anatomical match/mirror image).

Reaction Times. The analysis of reaction times (RTs, see Figure 3) revealed a main effect of action, $F(1,46) = 58.37$, $p < .001$, $\eta^2_p = .56$, and object, $F(1,46) = 10.61$, $p = .002$, $\eta^2_p = .19$. Participants detected tactile stimulation more quickly when they viewed contact compared to no contact, and when they viewed painful objects compared to non-painful objects. There was a trend towards an action by object interaction, $F(1,46) = 3.64$, $p = .063$, $\eta^2_p = .07$, and, crucially, a significant three-way interaction of viewpoint, action and object, $F(1,46) = 6.14$, $p = .017$, $\eta^2_p = .12$. No other main effects or interactions were significant ($F < 1.92$, for all).

To better understand the three-way interaction, RTs in the 1^{st} and 3^{rd} person perspective were analysed in separate 2 x 2 ANOVAs, with the factors of action (contact/no contact) and object (painful/not painful). Analysis of the 1^{st} person perspective trials confirmed the main effects of action, $F(1,47) = 52.67$, $p < .001$, $\eta^2_p = .53$, and of object, $F(1,47) = 4.75$, $p = .034$, $\eta^2_p = .09$, and the critical interaction of action and object, $F(1,47) = 7.65$, $p = .008$, $\eta^2_p = .14$. Indeed, planned comparisons indicated that in the 1^{st} person perspective, participants responded to touch on their own fingers more quickly when seeing painful grasps than in any other condition ($p < .002$ for all), fully replicating the results of Morrison et al. (2013). In contrast, analysis of the 3rd person perspective only revealed the known main effects of action ($F(1,47) = 41.31$, $p < .001$, $\eta^2_p = .47$) and object ($F(1,47) = 9.72$, $p = .003$, $\eta^2_p = .17$), but importantly, and in contrast to the 1st person perspective, no evidence for an interaction ($F(1,47) = 0.11$, $p = .737$, $\eta^2_p < .01$).

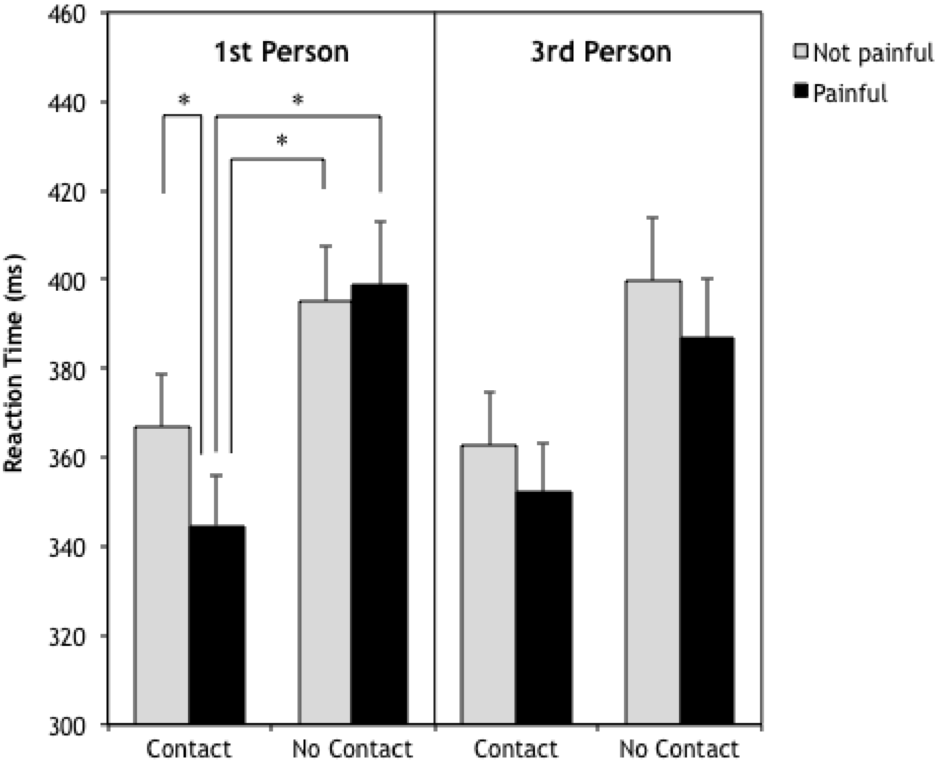

Figure 3. Mean reaction time (ms) to the detection of a tactile stimulus, whilst observing hands from 1st person perspective (left panel) and 3rd person perspective (right panel) grasp or miss painful and non-painful objects. Error bars represent +1SEM.

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Please see the Supplementary material for robustness analyses of the effects and their sensitivity to the inclusion of the 3rd person mapping factor, a signal detection analysis of the data, as well as an RT distribution analysis (de Jong, et al., 1994), showing that the three-way interaction develops from the fastest to the slowest responses.

False Alarms. In a version of the current task using close to threshold stimulation, Morrison et al. (2013) reported a bias to report touch during the observation even in the absence of stimulation (false alarms). The current experiment was an above threshold stimulation task, and, as such, did not promote participants to make false alarms in the same way an ambiguous stimulus might. Nevertheless, to investigate whether a similar pattern existed in the current data, false alarms were entered into the same three-way ANOVA as the reaction times. False alarms were recorded when participants pressed the spacebar to report they had felt stimulation, when no stimulation was delivered.

The number of false alarms (Figure 4) did not differ between viewpoint ($F < 2$) or object painfulness ($F < 1$), and no interaction between viewpoint and action ($F < 1$) was observed. There was no between group effect of 3rd person mapping (anatomical match/mirror image), $F(1, 46) = 1.59$, $p = .213$, $\eta^2_p = .03$, and no interaction with this factor. The ANOVA revealed a main effect of action, $F(1,46) = 17.34$, $p < .001$, $\eta^2_p = .27$, such that more false alarms were made when participants viewed hands making contact with objects ($M = 0.85$) than when the hands missed the objects ($M = 0.42$). There also was an interaction between viewpoint and object, $F(1,46) = 4.08$, $p = .049$, $\eta^2_p = .08$, suggesting that the 1st person perspective generally increased the likelihood for false alarms when viewing actions towards painful objects, compared to non-painful objects. Numerically, this effect appeared to be driven by the painful grasp condition and therefore mirrored the response time data.

However, the relevant three-way interaction between viewpoint, action and object was not significant, $F(1,46) = 1.04$, $p = .312$, $\eta^2_p = .02$.

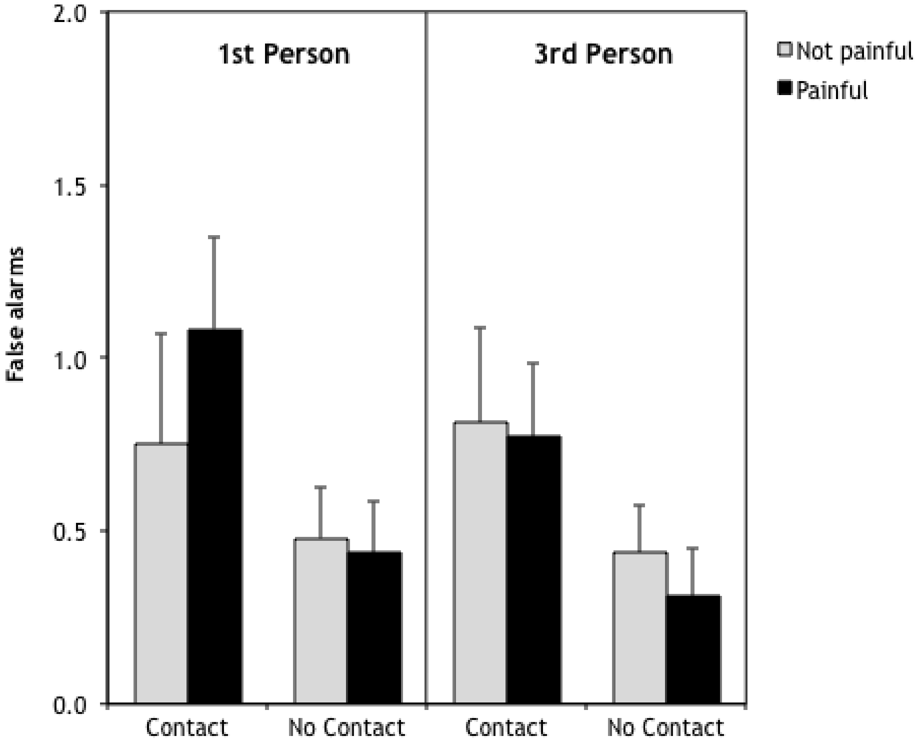

Figure 4. Mean number of false alarms (erroneous detections of tactile stimulation) whilst observing hands grasp or miss painful and non-painful objects from the 1st person perspective (left panel) or 3rd person perspective (right panel). Error bars represents +1SEM.

Hits. Hits reflected the percentage of correctly detected stimulations. Participants detected a mean of 27.43 ($SE = 0.14$) stimulation trials out of 28. There was no between group effect of 3rd person mapping (anatomical match/mirror image), $F < 1$, $p = .642$, $\eta^2_p < .01$. The three-way ANOVA revealed only one significant interaction between action and the between group

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effect of 3rd person mapping, $F(1,46) = 6.98$, $p = .01$, $\eta^2_p = .13$. Participants that viewed anatomically matching actions in the 3rd person perspective made more hits when viewing grasps compared to misses, $t(23) = 2.52$, $p = .019$, but not participants that viewed mirror images. However, this effect was not relevant for the key research question.

Discussion

Actors constantly predict the consequences of their own actions, based on an integration of action and object information (Johansson & Flanagan, 2009). The present study revealed that a similar integration happens during action observation. Participants reported tactile stimulation on their own fingers while watching hands grasp or not grasp painful or neutral objects. We found that tactile stimulation was detected more quickly when participants simultaneously viewed actions with painful consequences, compared to actions that did not cause pain. This happened even though sensory action consequences were not task relevant, and no direct cues to pain were given. Our data therefore reveal that sensory consequences are predicted "on the fly" during action observation, and – similar to action execution – emerge from a combination of object knowledge (whether it causes pain) with information about the observed action (whether it makes contact with the object), rather than from either of these aspects alone.

Importantly, this specific effect of observing action with painful consequences was restricted to the 1st person perspective, where the visual input matches the input one would receive from one's own actions. In the 3rd person perspective, the typical perspective we have on the actions of others, tactile responses only showed the more basic effects of whether the hand generally made contact with the object (irrespective of whether the object was painful), and whether the object was generally painful (irrespective of whether it was touched). In contrast to the 1st person perspective, the two aspects were not combined to predict the sensory consequences of the actions. These differences emerged even though the visual stimulation was identical in both conditions (i.e. the images were merely mirrored), and overall reaction times did not differ.

Our data therefore reveal that the 1st person perspective, but not the 3rd person perspective, provides privileged access to mechanisms that predict an action's sensory consequences by combining action and object knowledge. This finding challenges theories that assume that sophisticated shared representations of self and other emerge from specialist brain networks that have evolved to support the understanding of the actions of others (rather than the actions of oneself). Without further assumptions, such theories predict stronger effects in 3rd person settings. This is the typical viewpoint from which the actions of others are observed and therefore presents the adaptive challenge for which such mechanisms should be specialized (cf. Ramachandran & Oberman, 2008; Schütz-Bosbach, et al., 2006). Instead, our findings are in line with the idea that sensory predictions emerge from basic mechanisms that have evolved for monitoring the observer's own actions. The primary purpose of such mechanisms is predicting the consequences of these actions, such that negative outcomes are detected and course corrections can be made (Johansson & Flanagan, 2009; Csibra, 2007; Kilner et al, 2007; Miall, 2003). As was found here, they should therefore be specifically tuned to actions from the 1st person perspective, where the visual stimulation matches the typical input from one's own actions, but less so for the 3rd person perspective, which captures the typical viewpoint on the actions of others.

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As predicted, in the 1st person perspective, anticipation of painful action consequences sped up tactile detection on the participants' own fingers. This is consistent with the proposal that sensory consequences of others' actions are represented in the observers' own tactile representation systems. It specifically supports the view that somatosensory systems combine physical stimulation and stimulation predicted from the visual input in an additive manner, such that any response threshold can be reached more quickly when both are available (Morrison, et al, 2013; for evidence for a similar summation in the visual domain, see Roach, McGraw, & Johnson, 2011).

The data are unlikely to reflect more general contributions of heightened attention or sped up motor responses. To explain the specific effect of painful grasps, even such general effects must result from a prediction of painful action outcomes, based on the integration of object and action knowledge (rather than from either factor alone). In addition, several findings support the view that the effects reflect changes in sensory-tactile systems. First, in our prior work that established the current procedure (Morrison et al., 2013), the effect of painful grasps was observed only for the detection of tactile – but not auditory – targets, ruling out a general attention/arousal interpretation of the effect. Second, fMRI data confirmed that the effect was specific to the somatosensory cortices, rather than other neural systems (e.g., relating to visual perception, or motor output). Third, in the current study, the RT distribution analysis (Supplementary data) ruled out a mere priming of fast responses (i.e. due to an alerting response). Together, these results support the notion that our 1st person perspective effects indeed reflect a prediction of the sensory-tactile action consequences.

An important question is how predictive models that arose for the control of one's own action can account for effects of shared representation in 3rd person perspectives, which have been observed in a variety of studies, and which may form one basis of social understanding and empathy (e.g. Avenanti, et al., 2012). Our findings predict that, in the absence of biasing task factors, such effects should be restricted to basic components of other people's action, such as whether an object is generally painful, or whether a hand makes contact or misses. More sophisticated effects may require tasks or stimuli that encourage perspective taking and therefore make the 3rd person stimuli usable as input for 1st person prediction processes. For example, our prior work has revealed sophisticated sensory-tactile prediction effects even though actions were presented in a 3rd person perspective (Morrison et al., 2013). In that study, however, the participants were required to judge whether the action was appropriate to the object or not (grasping a painful object was inappropriate, and grasping a non-painful object was appropriate), a task that by itself biased participants to infer the actor's sensations.

Similar distinctions are also evident in the prior literature. Studies reporting automatic generation of shared representations in the 3rd person perspective have typically used internal states that could be directly gleaned from the stimuli without requiring integration across sources of information. In the context of tactile processing, for example, studies have manipulated whether a body part was touched or not, without manipulating the type of object (e.g., Keysers et al., 2004; Schaefer, et al., 2009), or they varied the painfulness of an object, without manipulating whether it was touched or not (Meyer, et al., 2011). In contrast, many of the more sophisticated effects have been shown to be modulated by either encouraging or disrupting perspective taking. For example, automatic imitation (e.g. Brass, Bekkering, Wohlschläger, & Prinz, 2000) is disrupted if participants are made aware that the stimuli are virtual and do not belong to a sentient agent (Longo & Bertenthal, 2009), but is enhanced by prior social interaction (Hogeveen & Obhi, 2012). Pain empathy and prediction of others' future behavior only engages self-related brain areas when the observed people were similar to the participants or belonged to the same social group (e.g., Mitchell et al., 2006; Avenanti, Sirigu, & Aglioti, 2010). Finally, an important modulatory factor is relevance for one's own action planning. The curvature of an observed reach over an obstacle only affected the observers' reach when the two actors shared a workspace (Griffiths & Tipper, 2012) or when the viewed action was in the observer's own peripersonal space (Griffiths & Tipper, 2009). Thus, together, these observations are in line with our findings and suggest that deriving sophisticated shared representation of other people's internal states from a 3rd person perspective is not automatic, but depends on a motivation for perspective taking.

Conclusions

Shared representations have been demonstrated for almost all aspects of others' internal states, and they have been shown to form a basis of social understanding and empathy, but the origin of these mechanisms – and the boundary conditions for their activation – are still unclear. Here, we found that automatic predictions of the tactile-sensory consequences of others' actions only occurred in the 1st person perspective, suggesting a specific role for mechanisms predicting the outcome of ones' own actions. In contrast, our data suggest that the prediction of sensory action consequences in 3rd person perspectives is under cognitive control, and may only happen when perspective taking promotes deeper encoding of the actions.

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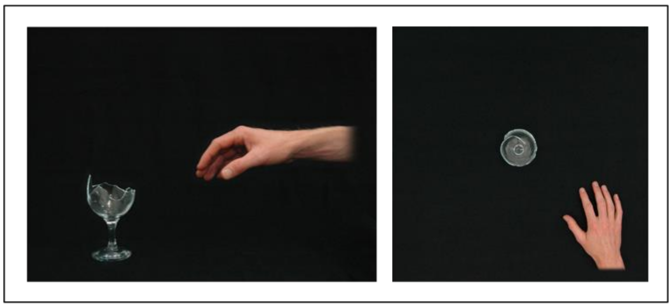
Supplementary Material

Supplementary Figure 1



Supplementary Figure 1. Example images from the 28-item rating scale questionnaire. Participants first saw the image of the object from a typical viewing perspective to ensure they recognized the object when it was viewed from the less familiar birds-eye view. The rating was made during the second frame, where the object was shown from a bird's eye perspective.

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Robustness analysis and sensitivity to the inclusion of the 3rd person mapping factor

None of the critical main effects or interactions – action, object, action X object, action, viewpoint X action X object – was qualified by the between-participants factor of 3rd person mapping (whether participants viewed the actions in the 3rd person perspective as a mirror image or as an anatomical match), $F < 1$, for all. Moreover, the results were statistically identical when this factor was omitted from the ANOVA model, both for the omnibus ANOVA (relevant three way interaction of object, action and perspective, $F(1,47) = 6.22$, $p = .016$), and for the relevant two-way interactions of action and object, which is present in the 1st person trials, $F(1,47) = 7.65$, $p = .008$), but absent in the 3rd person perspective trials, $F(1,47) = 0.11$ $p = .737$. The lack of sensitivity to the inclusion/exclusion of the factor suggest that our results are not driven by one perspective in particular, and that the mapping used for presenting the actions in the 3rd person perspective has no measurable direct effect on the tactile detection times.

To further verify that the effects are comparable across both mappings, we analysed the response time data separately for both groups of participants (Supplementary Figure 2, see Supplementary Figure 3 for the False Alarm data), those that saw mirror images or anatomical matches of the original actions in the 3rd person perspective ($n = 24$, for each). Again, these analyses revealed little to no sensitivity of our results to whether the actions in the 3rd person perspective were presented as an anatomical match or a mirror image. The relevant three-way interaction – indicating stronger integration of object and action information in the 1st person than the 3rd person perspective – was significant for the mirror image group, $F(1,23) = 4.43$, $p = .047$, $\eta^2_p = .161$, and showed a numerically identical pattern for the anatomical match group, even though this test failed to reach conventional levels of

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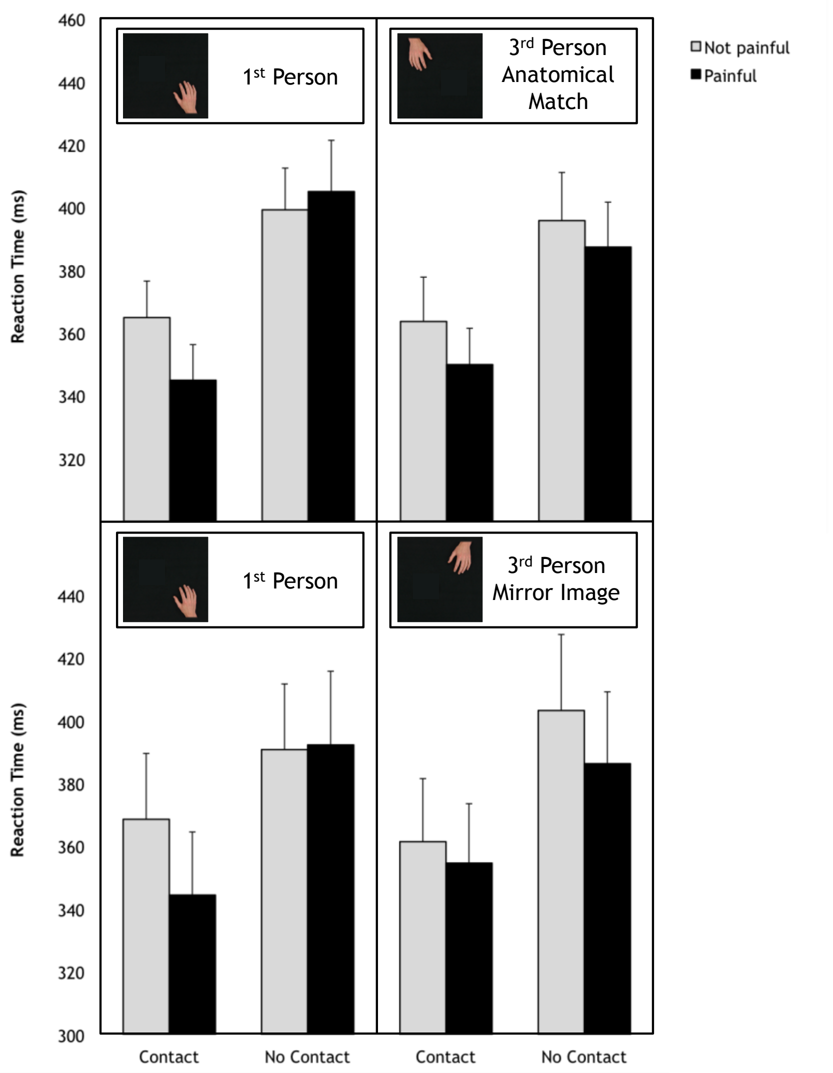
significance, *F*(1,23) = 1.86, *p* = .186, η^2_p = .075. Indeed, there was no evidence for a difference between the effects for the two groups of participants, *F*(1,23) = 0.46, *p* = .503.

In addition, despite the limited power, the critical two-way-interaction of action and object was found for both groups in the 1st person perspective (mirror image, *F*(1, 23) = 3.61, *p* = .070, η^2_p = .14; anatomical match, *F*(1,23) = 3.89, *p* = .061, η^2_p = .15), but was absent for both groups in the 3rd person perspective (mirror image, *F*(1,23) = 0.87, *p* = .360, η^2_p = .04; anatomical match, *F*(1,23) = 0.33, *p* = .572, η^2_p = .01), further confirming that our effects do not depend on how the 3rd person actions were presented.



Supplementary Figure 2. Mean reaction time (ms) to the detection of a tactile stimulus, whilst observing hands from 1st person perspective and 3rd person perspective interact with painful and non-painful objects, for participants that saw anatomically matching images in the 3rd person perspective (top panel) and participants that saw mirror images in the 3rd person perspective (lower panels). Error bars represent +1SEM.

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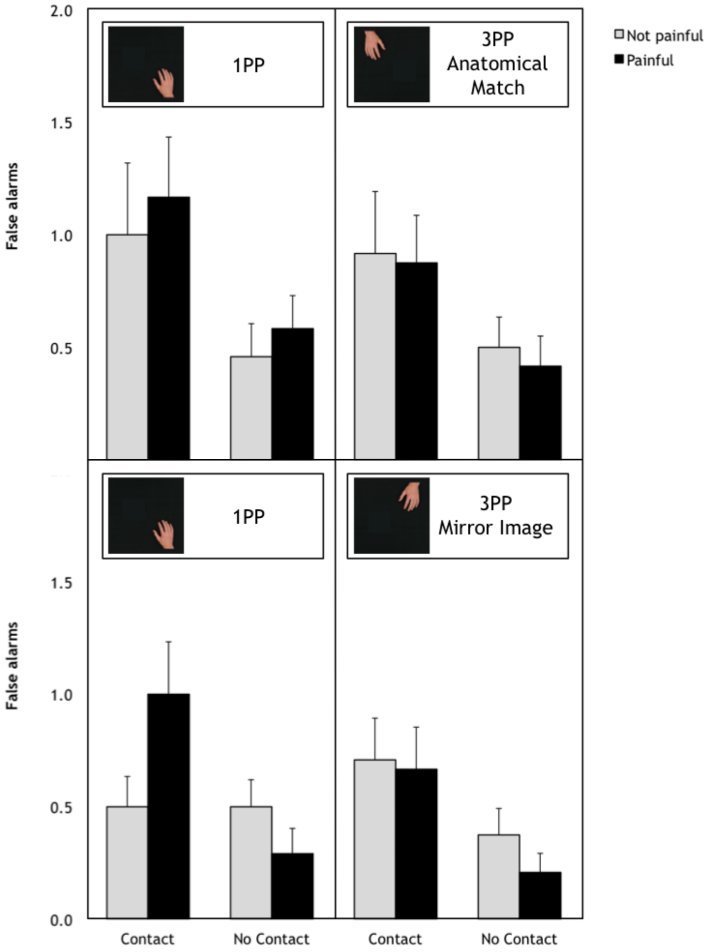

Supplementary Figure 3. Mean number of false alarms (erroneous detections) to the detection of a tactile stimulus, whilst observing hands from 1st person perspective and 3rd person perspective interact with painful and non-painful objects, for participants that saw anatomically matching images in the 3rd person perspective (top panel) and participants that saw mirror images in the 3rd person perspective (lower panels). Error bars represent +1SEM.

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RT distribution analysis.

We assumed, based on our prior work (Morrison, et al, 2012), that our RT effects reflect changes in the readiness to detect sensory stimulation, rather than a mere readiness to respond quickly to any sensory input when anticipating pain (i.e. a general alerting response priming fast movements). That is, our effects were specific to tactile detection and not observed when detecting auditory targets. To further support this notion, we analysed how the RT-effect developed over time, by assessing the size of the effect across response quartiles. General response priming accounts predict that any effects would be driven specifically by the faster responses (evidence for such an early effect, see, de Jong, et al., 1994), while a perceptual effect would predict an effect that stays constant or that develops over time.

To disentangle these possibilities, we utilized the procedure of de Jong and colleagues (1994). For every participant, and each of the eight different conditions (Viewpoint x Action x Object), we split the data into four bins, ordered from the fastest 25% to the slowest 25% of responses. We then ran a four-way ANOVA with the factors Action (grasp, miss), Object (painful, neutral), Viewpoint (1^{st} person, 3^{rd} person), and Bin (1, 2, 3, 4). This indeed revealed a marginally significant four-way interaction of Action, Object, Perspective and Bin, $F(1,47) = 3.09$, $p = .077$). Supplementary Figure 4 plots this effect. Each line marks the two-way-interaction effect of Action and Object for the two conditions in milliseconds, that is, the extent to which painful (relative to neutral) objects sped up tactile detection times when they were grasped compared to when they were missed. The difference between both lines therefore marks the 3-way interaction of perspective, action, and object in each bin.

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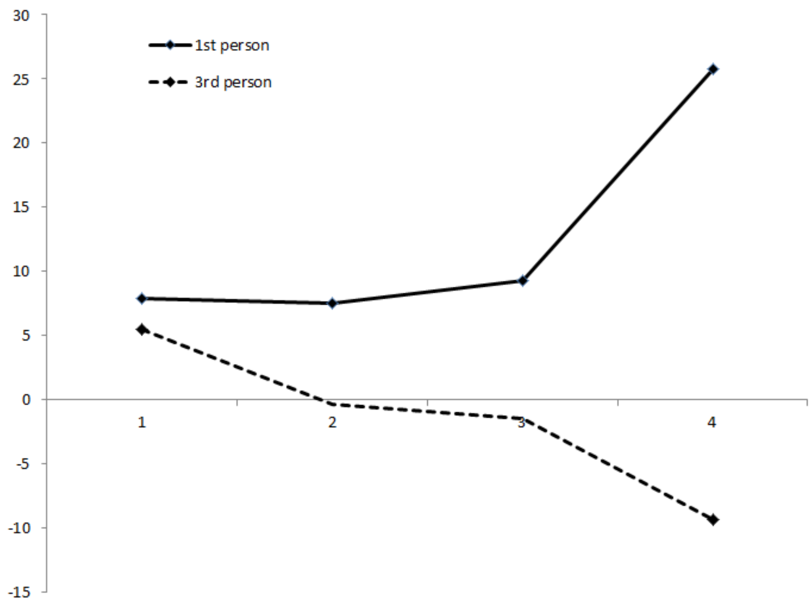

Supplementary Figure 4. The size of the two way interaction of action and object in milliseconds across the four response quartiles (from the 25% fastest to the 25% slowest responses), for action seen from the 1st person perspective (solid line) and action seen from the 3rd person perspective (dotted line). Filled dots on each line mark effects at least marginally significantly different from zero in simple t-tests (p < .10).

As can be seen, the effect indeed increases in the 1st person perspective, but does, if anything, decrease in the 3rd person perspective. Indeed, pairwise t-tests show that, for the first 25% of responses, the effect in both perspectives cannot be distinguished (p = .567). In the 2nd and 3rd bins, the differences just failed to reach conventional levels of significance (p = .077, p = .114 respectively). Only in the last bin, were significant differences found (p = .031). This shows that the differential effect of seeing grasps of painful objects in the two perspectives increases with response time. This is not consistent with the idea of a general alerting response that would prime participants to make relatively quick responses, but supports the notion of a perceptual effect that develops over time in the 1st person relative to the 3rd person perspective.

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Signal Detection Analysis

In contrast to Morrison et al. (2013), our present paradigm was not designed for a signal detection analysis and is not appropriate for it, for several reasons: (1) we used an above threshold task, so variability is low and there are too many cells with 100% hits and 0% false alarms. For a signal detection analysis, such cells have to be manually adjusted, which contaminates the data. (2) Typically, for signal detection analysis, 40 trials per condition are required, but we have only 28 stimulation trials per condition (35 in total). (3) The proportion of signal and noise trials is unbalanced (28 to 7), which further exacerbates the contaminations introduced by the manual adjustments.

Nevertheless, after the request of a reviewer, we ran such an analysis, and the results support the findings of our previous study (Morrison et al., 2013). We report the most important results here, but given the considerations above, they should be interpreted with caution. First, analysis of d-prime shows a significant Perspective by Object interaction, F = 4.64, p = .037, replicating the effect shown in the false alarms, and indicating that people are less able to distinguish stimulation from no stimulation when painful objects are being acted upon in a 1st person perspective. Second, the bias measure revealed a marginally significant three-way interaction of Object, Action, and Perspective, F = 3.44, p = .070. This reflects a higher tendency to report stimulation in the painful grasp condition in the 1st person perspective only (similar to what was found for the RT data). This effect replicates our previous findings (Morrison, et al., 2012), where such an effect was predicted if the predicted sensory consequences and actually experienced stimulation would summate, leading to sensations of touch in the absence of stimulation (for similar effects in the visual domain, see Roach, McGraw, & Johnson, 2011). Consistent with this interpretation, in the original study, this effect was absent in a control experiment where visual stimulation was identical but participants now had to detect auditory targets.