Are the spatial features of bodily threat limited to the exact location where pain is expected?

Charlotte Vanden Bulcke[a], Geert Crombez[a],

Charles Spence[b], & Stefaan Van Damme[a]

[a] Department of Experimental-Clinical and Health Psychology, Faculty of Psychology and Educational Sciences, Ghent University, Henri Dunantlaan 2, 9000 Ghent, Belgium.

[b] Crossmodal Research Laboratory, Department of Experimental Psychology, University of Oxford, 9 South Parks Road, Oxford, UK.

Corresponding author:

Charlotte Vanden Bulcke**,** Ghent University, Faculty of Psychology and Educational Sciences, Department of Experimental-Clinical and Health Psychology, Henri Dunantlaan 2, 9000 Ghent, Belgium.

E-mail: Charlotte.VandenBulcke@UGent.be

Phone number: +32(0)9-264 91 06. Fax: +32(0)9-264 64 89.

Abstract

Previous research has revealed that anticipating pain at a particular location of the body prioritizes somatosensory input presented there. The present study tested whether the spatial features of bodily threat are limited to the exact location of nociception. Participants judged which one of two tactile stimuli, presented to either hand, had been presented first, while occasionally experiencing a painful stimulus. The distance between the pain and tactile locations was manipulated. In Experiment 1, participants expected pain either proximal to one of the tactile stimuli (on the hand; near condition) or more distant on the same body part (arm; far condition). In Experiment 2, the painful stimulus was expected either proximal to one of the tactile stimuli (hand; near) or on a different body-part at the same body side (leg; far). The results revealed that in the near condition of both experiments, participants became aware of tactile stimuli presented to the "threatened" hand more quickly as compared to the "neutral" hand. Of particular interest, the data in the far conditions showed a similar prioritization effect when pain was expected at a different location of the same body part, as well as when pain was expected at a different body part at the same body side. In this study the encoding of spatial features of bodily threat was not limited to the exact location where pain was anticipated, but rather generalized to the entire body part and even to different body parts at the same side of the body.

Key words (max. 6): attention -TOJ- experimental pain-hypervigilance-bodily threat-attentional set

1. Introduction

Imagine a man playing football who suddenly experiences an intense, shooting pain in his leg after a vigorous tackle. There is a high chance that this pain will capture his attention and interrupt his game. In this example, the capture of attention by pain can be thought of as a stimulus-driven or bottom-up effect (Gallace & Spence, 2014; Legrain et al., 2009; McGlone, Lloyd, & Tipper, 1999). Many studies have already demonstrated that attention is unintentionally captured by pain when it is intense, unpredictable, and/or novel (Crombez, Baeyens, & Eelen, 1994; Eccleston & Crombez, 1999; Legrain et al., 2012). However, the bottom-up capture of attention by pain can be modulated by goal-directed or top-down variables, as when pain is the subject of a person's current goals, thoughts, and/or intentions (Crombez, Van Damme, & Eccleston, 2005; Van Damme, Legrain, Vogt, & Crombez, 2010). Imagine another football player who has recently recovered from a serious ankle injury. When starting to play football again, being fearful of re-injury, he may focus his attention on the injured body part and, hence, quickly become aware of any – even innocuous – bodily sensation that may occur there. As such, attention to pain may be the result of the interplay between bottom-up and top-down factors in a similar way to what has also been extensively reported in the context of visual attention (Desimone & Duncan, 1995; Yantis, 2000).

According to the neurocognitive model of attention to pain (Legrain, et al., 2009), the top-down modulation of attention to somatosensory information occurs by means of the activation of an attentional set. This is defined as the set of stimulus features that participants keep in working memory to identify goal-relevant information. When a stimulus, even when it is not particularly salient, happens to match one of the features in the attentional set, it is more likely to be selected for further processing (Downman, 2001; Folk, Remington, & Johnston, 1992; Van Ryckeghem, Crombez, Eccleston, Legrain, & Van Damme, 2013; Yantis, 2000; Zampini et al., 2007). Thus, when one expects pain to occur, a stimulus that shares features with pain,

such as its sensory modality or its stimulus location, may also be preferentially attended to (Legrain, et al., 2009).

To date, few studies have attempted to investigate this idea. Crombez and his colleagues (Crombez, Eccleston, Baeyens, & Eelen, 1998) investigated the interruptive effect of mild experimental pain stimuli on the performance of a cognitive task. Pain stimuli could be administered to either arm, and participants were led to believe that on one arm a very intense, painful stimulus could sometimes occur. Interestingly, the interruptive effect was significantly larger when a pain stimulus arrived at the "threatened" arm in comparison to the other arm, although on both arms only mild stimuli were actually presented. Recently Vanden Bulcke, Van Damme, Durnez, and Crombez (2013) specifically examined whether experimentally induced threat of pain would speed up the processing of innocuous tactile stimuli presented at the bodily location where the painful stimulus was expected, using a Temporal Order Judgment (TOJ) paradigm. Participants indicated which one of two tactile stimuli administered to each hand, had been presented first. Crucially, the participants expected that a painful stimulus would occasionally be administered on one of their hands. The results revealed that the participants became aware of tactile stimuli on the "threatened" hand more quickly than on the "neutral" hand.

While the results of these previous studies (Crombez et al., 1998; Vanden Bulcke et al., 2013) are consistent with the idea of top-down prioritization of the pain-related bodily location, it is as yet unclear how specific the spatial features of bodily threat are encoded in the attentional set. If only the *exact* location of the pain is encoded, top-down prioritization should be limited to those somatosensory inputs that are in close proximity to the specific bodily location where the painful stimulus is expected. However, it is also possible that the spatial features of bodily threat are encoded in a more general manner, for instance, in terms of the body part where the painful stimulus is anticipated, or in terms of the side of the body

where the pain is expected. The aim of the present study was to investigate the specificity of the spatial features of pain in the attentional set. We report two experiments in which a tactile TOJ task was used for stimuli presented to the hands. In the first experiment, a painful stimulus was occasionally administered, either proximal to one of the tactile stimuli, i.e., the hand (near condition), or more distant on the same body part, i.e., the arm (far condition). In the second experiment, a painful stimulus was occasionally administered either proximal to one of the tactile stimuli, i.e., the hand (near condition) or on a different body part at the same body side, i.e., the leg (far condition). With regard to the "near" condition, we hypothesized that in both experiments, tactile stimuli would be perceived more rapidly on the "threatened" hand than on the "neutral" hand (see also Van Damme, Gallace, Spence, Crombez, & Moseley, 2009; Vanden Bulcke et al., 2013). With regard to the "far" condition, we examined whether tactile stimuli would be perceived more rapidly on the hand of the "threatened" arm (Experiment 1) or the hand ipsilateral to the threatened leg (Experiment 2), than on the other hand.

2. Experiment 1

2.1 Methods

2.1.1. Participants

Thirty-four undergraduate students (25 females, 9 males; mean age = 20.4 years; all white Caucasian) participated to fulfill course requirements. All of the participants had normal or corrected-to-normal vision and normal hearing. All but three of the participants reported being right-handed. The participants rated their general health on average as 'good' and none of the participants reported having a current medical condition or mental disorder. Although a student group is often described as healthy, pain can be a prevalent symptom amongst this group, and is therefore best documented. Twenty-eight of the participants reported having experienced pain during the last six months (average of 24.3 days in 6 months). Thirteen of

these participants reported feeling pain at the time of testing, but the average rating of the intensity of this pain was low (M = 2.91; ranging from 1 to 6, SD = 1.44) on a Likert scale where 0 indicated 'no pain' and 10 the 'worst pain ever'. All of the participants gave their informed consent and were free to terminate the experiment at any time should they so desire. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University. The experimental session lasted for approximately 1 hour.

2.1.2 Apparatus and materials

Tactile stimuli (10 ms duration; 200Hz) were presented by means of two resonant-type tactors (C-2 TACTOR, Engineering Acoustics, Inc., Florida, http://www.eaiinfo.com/) consisting of a housing of 3.05 cm diameter and 0.79 cm high, with a skin contactor of 0.76 cm diameter. Prior to the start of the experiment, the perceived stimulus intensities at both tactor locations were individually matched (Weinstein, 1968). This was done by means of a double random staircase procedure, based on the 'simple up-down method' of Levitt (1971). In a first phase, 24 stimuli presented on the left hand were judged relative to a reference stimulus, which was defined as the maximum intensity (power = 0.21 Watt) on a 5-point Likert scale ranging from 1 ('no sensation') to 5 ('maximum intensity'). The intensity that elicited an averaged rating of 3 was used as the stimulus intensity for the left hand, and was the reference stimulus for the second phase. In the second phase, 24 stimuli on the right hand were judged relative to the reference stimulus on the left hand, once again using a 5-point Likert scale (1 = 'much weaker', 2= 'weaker', 3= 'equally strong', 4= 'stronger', 5= 'much stronger'). The stimulus intensity that elicited an averaged rating of 3 was used as the intensity of the stimulus at the right hand.

Painful stimuli were delivered by means of two constant current stimulators (Digitimer DS5 2000, Digitimer Ltd, England, http://www.digitimer.com/index.htm). Each stimulator

consisted of trains of 20 ms sinusoid pulses with a frequency of 50 Hz and a duration of 200 ms. Painful stimuli were delivered via two pairs of lubricated Fukuda standard Ag/AgCl electrodes, each pair consisting of an anode and cathode (1 cm diameter). One pair of electrodes was attached on the forearm, the other pair of electrodes on the hand. The intensity of the electrocutaneous stimuli was determined for each participant individually by means of a random staircase procedure. For each hand, 20 electrocutaneous stimuli were presented to participants (starting intensity between 0 and 1.5 mA) and self-reports were collected on an 11-point Likert scale (0 = 'no sensation'; 10 = 'unbearable pain'). The pain intensity that elicited an average rating of 7 was selected as the pain stimulus for the main experiment (Arntz, Dreessen, & De Jong, 1994; Vanden Bulcke et al., 2013).

The task was programmed and controlled by the INQUISIT Millisecond software package (Inquisit 3.0, Millisecond Software LLC, Seattle, WA, http://www.millisecond.com//) on a laptop (HP Compaq nc 6120).

2.1.3 TOJ Paradigm

In the TOJ task (Piéron, 1952), two tactile stimuli were administered, one on either hand, separated by one of 10 randomly assigned stimulus onset asynchronies (SOAs) ranging from -120 to +120 ms (-120, -60, -30, -15, -5, +5, +15, +30, +60, +120 ms; negative values indicate that the left hand was stimulated first) (see also Vanden Bulcke et al., 2013). The participants were instructed to report aloud the hand on which the first tactile stimulus was presented, and the experimenter registered the answers using a keyboard. A trial started with the presentation of a fixation cross (1000 ms) in the middle of the screen, followed by a colored cue (either blue or yellow, of 1000 ms duration), indicating whether or not a painful stimulus could follow on one specific location (threat and control trial, respectively). Which color of cue was associated with threat was counterbalanced across the participants. Before the start of each block of trials, the participants were told on which location (hand or forearm) they should

expect the painful stimulation to be delivered. In 10% of the threat trials, the pain stimulus was actually delivered instead of the two tactile stimuli (pain trials), but the participants were not informed about this contingency. The participants were informed that no response had to be given in such trials.

2.1.4. Procedure

Upon arrival at the laboratory, the participants received the task instructions and were told that an electrocutaneous stimulus would be used during the experiment and that "most people find this kind of stimulation unpleasant" (Crombez, et al., 1998; Van Damme, Crombez, & Eccleston, 2004a). After the participants had given their written informed consent, they were seated in front of the experimental apparatus. Their forearms were positioned symmetrically on the table. The tactors were placed on the dorsal side of their hand, with the center on the middle of the third metacarpal. One pair of electrodes was attached on the hand dorsum between thumb and index finger, in the sensory territory of the superficial radial nerve. The other pair of electrodes was placed on the proximal third of the muscle belly of the brachioradialis of the same limb (approximately 3 cm below the lateral epicondyle). To visualize the brachioradialis, the participants were asked to flex the elbow with the forearm in pronation, while the experimenter provided resistance against the distal end of the radius. As such, the muscle belly of the brachioradialis is well visible and enables the experimenter to attach the electrode exactly on the muscle belly. The skin at the electrode sites was first abraded with a peeling cream (Nihon Kohden, Tokyo, Japan) to reduce the resistance of the skin. The participants were informed that they would have to decide on each trial which stimulus had been presented first. The accuracy of participants' responses was emphasized, rather than the speed. The participants wore headphones (Wesc, Conga) during the experiment. White noise (42.2 dB) was presented continuously through headphones to mask

the noise resulting from the operation of the tactors. The participants were not given any feedback concerning their performance.

The session began with a practice block of twenty-three trials (1 trial per SOA for control trials, 1 trial per SOA for threat trials, 3 pain trials). Following this, four blocks of 105 trials (5 trials per SOA for control trials, 5 trials per SOA for threat trials, 5 pain trials) were presented. The two possible pain locations (hand or arm) were alternated between blocks and the order was counterbalanced between participants. The side on which pain was expected (left vs. right limb) was counterbalanced between participants.

2.1.5 Self-report measures

After each test phase, the participants had to rate several questions concerning their concentration ('To what extent have you made an effort to perform this task?', 'To what extent did you concentrate on this task?'), attention to painful/tactile stimuli ('To what extent did you pay attention to the painful/tactile stimuli?'), pain experience ('How painful did you find the electrocutaneous stimuli?'), anxiety ('How anxious were you during this block?'), fatigue ('To what extent did you find this task tiring?') on eleven-point numerical rating scales (anchored 0 = not at all and 10 = very strongly). As a manipulation check, we were especially interested in the participant's ratings of fear ('To what extent were you afraid that a painful stimulus would be administered by the blue/yellow cue?') and expectations ('To what extent did you expect that a painful stimulus would be administered by the blue/yellow cue?'). Before the experiment, the participants were asked to complete the Pain Vigilance and Awareness Scale (PVAQ; McCracken, 1997; Roelofs, Peters, Muris, & Vlaeyen, 2002) and the Pain Catastrophizing Scale (PCS; Sullivan, Bischop, & Pivik, 1995; Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002). These data were collected for meta-analytical purposes and are not reported in detail here.

2.1.6 Data analysis

In TOJ studies, it is common practice (Shore, Gray, Spry, & Spence, 2005; Spence, Shore, & Klein, 2001) to exclude those participants from statistical analysis when (1) any of the PSS values is greater than the highest SOA (± 120 ms) tested, (2) participants have less than 80% accuracy on the trials with the largest SOA tested (± 120 ms). Four participants (women, all right-handed) had to be excluded for the first reason, one participant (female, right-handed) for the second reason. Trials following trials with electrocutaneous stimulation were removed from subsequent data analysis in order to avoid the possibility that: (1) potential effects would be mainly driven by trials directly following painful stimulation; or (2) after-effects of pain would interfere with the tactile TOJ (max. 10% of all trials).

The analyses were based on a procedure that has been commonly described in the literature (Shore et al., 2005; Spence et al., 2001; Van Damme et al., 2009). The proportions of 'left-hand-first' and 'right-hand-first' responses for threat presented on the left and right side, respectively, for all trials at each SOA, were converted into the corresponding z-scores using a standardized cumulative normal distribution (probits). The best-fitting straight line was computed for each participant and the derived slope and intercept values were used to compute the point of subjective simultaneity (PSS) values for the subsequent statistical analyses (see Figure 1). The PSS refers to the point at which observers report the two events (right hand first and left hand first) equally often. This is commonly taken to be equivalent to the (virtual) SOA at which participants perceive the two stimuli as occurring at the same time and such equivalent to the SOA value corresponding to a proportion of *left/right hand first responses* of 0.5. The PSS is computed as the opposite of the intercept divided by the slope from the best-fitting straight line. The sign of the PSS in which threat was presented on the right hand was reversed. Subsequently, for each participant, the final PSS values was calculated by taking the average of the PSS values for threat presented on the left side and the reversed PSS values for threat presented on the right side. Hence, a positive value indicates

that the stimulus contralateral to the side of threat had to be presented first in order for both stimuli to be perceived as simultaneous. As a result, a positive PSS indicates that stimuli on the threatened hand are perceived more rapidly than those presented to the other hand. In sum, the PSS provides information concerning biases in spatial attention resulting from the presentation of bodily threat. A repeated measures analysis of variance (ANOVA) with the factors Cue (within; threat versus control), Location (within; near versus far) and Pain Side (between; left versus right) was performed on the PSS data. For ease of comparison with the norms of Cohen (1988), we calculated effect sizes for independent samples using the formula of Dunlap and colleagues (Dunlap, Cortina, Vaslow, & Burke, 1996). For interaction effects, difference scores were used to obtain Cohen's d. A difference score was calculated for threat versus control trials, which was then compared between the near and far condition. We determined whether Cohen's *d* was small (0.20), medium (0.50), or large (0.80) (Cohen, 1988). We also report the 95% confidence intervals (95% CI) of the effect sizes.

Insert Figure 1 about here

2.2 Results

2.2.1 Manipulation check

Participants reported being more afraid during the threat trials (M = 5.70, SD = 2.51) than during the control trials (M = 0.19, SD = 0.40) (t_{28} = 12.45, $p < 0.001$; d = 2.56 [95% CI: 1.73, 3.39]). Furthermore, the participants reported a higher expectation of a painful electrocutaneous stimulus during threat trials (M = 5.78, SD = 2.26) than during control trials (M = 0.32, SD = 0.68) (t_{28} = 12.93, $p < 0.001$; d = 3.10 [95% CI: 1.99, 4.21]). Finally, the participants rated the electrocutaneous stimuli as moderately painful (M = 5.81, SD = 2.11).

2.2.2 PSS

The main effect of Cue was significant ($F(1,27) = 6.04$, $p = 0.02$), with threat trials (M = 20 ms, SD = 34) showing a larger PSS than control trials (M = 9 ms, SD = 24) ($d = 0.36$ [95% CI: 0.03,0.70]). The main effect of Location was not significant ($F(1,27) = 0.91$, $p = 0.35$) ($d = 0.10$ [95% CI: -0.15,0.35]), meaning that, on average, the PSS was similar in the near and far conditions (M = 16 ms; SD = 28 and M = 13 ms; SD = 31, respectively) (see Figure 2). Of particular interest, there wasn't a significant interaction between Cue and Location ($F(1,27) = 0.65$, $p = 0.43$) ($d = 0.16$ [95% CI: -0.21,0.52]), indicating that the difference in PSS between the threat trials and control trials was similar in both the near and the far conditions. Note that there was a significant effect of the Side of the Pain ($F(1,27) = 6.41$, $p = 0.02$), larger PSS values were observed in subjects who attended the pain on the left side (M = 25 ms; SD = 29) as compared to PSS values in subjects who attended pain on the right side (M = 5 ms; SD = 27) ($d = 0.74$ [95% CI: 0.16, 1.33]).[1] However, the Side on which the Pain was delivered did not interact with the hypothesized effects. Thus it can be concluded that the threat effects were independent of the side of the body that was threatened. None of the other interactions were significant.

Insert Figure 2 about here

[1] To check whether differences in perceived and physical pain intensities between the two groups could account for the main effect of side of pain, we conducted a series of independent t-tests. We found no significant differences in perceived intensity (per) of the *painful* stimuli between participants who received painful stimulation on the left ($M_{hand} = 5.85 \pm 2.36$; $M_{arm} = 6.96 \pm 2.37$) of right side ($M_{hand} = 5.69 \pm 2.20$; $M_{arm} = 6.09 \pm 2.09$) of the limb ($t_{perhandleft,\ perhandright}(27) = 0.19$ $p = 0.85$, $t_{perarmleft,\ perarmright}(30) = 1.03$ $p = 0.31$) nor in physical intensity (phy) of the *painful* stimuli between participants who received painful stimulation on the left ($M_{hand} = 2.16$ mA ± 0.68; $M_{arm} = 2.26$ mA ± 0.63) of right side ($M_{hand} = 2.35$ mA ± 0.38; $M_{arm} = 2.51$mA ± 0.60) of the limb ($t_{phyhandleft,\ phyhandright}(27) = -0.89$ $p = 0.39$, $t_{phyarmleft,\ phyarmright}(30) = -1.12$ $p = 0.28$). Furthermore, paired-sampled t-test indicated no significant differences in perceived intensity (per) and physical intensity (phy) of the *tactile* stimuli between the left and right hand ($t_{per}(28) = -1.38$ $p = 0.18$; $t_{phy}(28) = 0.48$ $p = 0.63$). Moreover, no significant differences were found in physical as well as perceived intensity of the tactile stimuli between the left and right hand for participants who received painful stimulation on the left neither for participants who received painful stimulation on the right side of the limb ($t_{perpainleft}(13) = -1.27$ $p = 0.23$; $t_{perpainright}(14) = -0.62$ $p = 0.55$; $t_{phypainleft}(13) = 1.38$ $p = 0.19$; $t_{phypainright}(14) = -0.94$ $p = 0.36$).

2.3 Interim discussion

The results of Experiment 1 demonstrate that when participants made judgments regarding which of two tactile stimuli had been presented first, stimuli presented on the hand on which pain was expected were perceived more rapidly than stimuli presented on the "neutral" hand. Thus, in line with our previous research (Vanden Bulcke et al., 2013), it was shown that when participants anticipated pain at a particular location of the body, they became more quickly aware of somatosensory signals at that bodily location. Of specific interest, even when pain was anticipated at the arm, tactile stimuli on the hand of the "threatened" arm were perceived more rapidly than tactile stimuli on the other hand. In this experiment, the findings suggest that the encoding of spatial features of bodily threat may not be limited to the exact location where pain is anticipated. In our second experiment, we investigated whether the prioritization of tactile stimuli on the hand is still present even when bodily threat is induced on more extreme distant body parts on the same side of the body, for example on the leg. Therefore, in Experiment 2, a painful stimulus was occasionally administered either proximal to one of the tactile stimuli, i.e., the hand (near condition) or on a different body part at the same body side, i.e., the leg (far condition). As in the first experiment, the participants had to decide which one of two tactile stimuli had been presented first.

3. Experiment 2

3.1 Methods

3.1.1 Participants

Thirty-four undergraduate students (29 female and 5 male; mean age, 21.94 years; all white Caucasian) took part in this study. The participants were given 8 Euros in return for taking part. All of the participants had normal or corrected-to-normal vision and normal hearing. All but 5 were right-handed by self-report. Twenty-six participants reported having experienced pain during the last six months (average of 19.08 days in 6 months). Fifteen of

these participants reported feeling pain at the time of testing, but the average rating of the intensity of this pain was low (M = 2.69; ranging from 1 to 8, SD = 2.27) on a Likert scale where 0 indicated '*no pain*' and 10 indicated the '*worst pain ever*'. The participants rated their general health on average as '*very good*' and none of them reported having a current medical or mental disorder. All of the participants gave their informed consent and they were free to terminate the experiment at any time. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University. The experimental session lasted for approximately 1 hour.

3.1.2. Apparatus and materials

The same apparatus and stimulus characteristics were used as in Experiment 1.

3.1.3 TOJ Paradigm

The task was identical to Experiment 1, with the exception that the participants received the electrocutaneous stimuli on the hand in half of the blocks, whereas in the other half of the blocks, they were presented to the musculus tibialis anterior (ankle) instead.

3.1.4 Procedure

The procedure was almost identical to that used in Experiment 1. One pair of electrodes was attached on the dorsum of the hand, between the thumb and index finger, in the region of the superficial radial nerve. The other pair of electrodes was placed on the distal part of the musculus tibialis anterior, which was standardized at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus. To control of the exact location, the musculus tibialis anterior was visualized by asking an active dorsal flexion in the ankle while sitting on an examination table.

3.1.5 Self-report measures

The questionnaires and self-report measures were the same as in Experiment 1.

3.1.6 Data analysis

The measures and the analyses of the data were identical to Experiment 1. Again, the best-fitting straight line on the z-scores was computed for each participant and the derived slope and intercept values were used to compute the point of subjective simultaneity (PSS) values for the subsequent statistical analyses (see Figure 3).

Exclusion criteria were the same as for Experiment 1. Three of the participants (all women, two right-handed and one left-handed) had an accuracy of less than 80% on those trials with the largest SOA tested (± 120 ms) and were therefore removed from data analysis.

Insert Figure 3 about here

3.2 Results

3.2.1 Manipulation check

Participants reported being more afraid during threat trials (M = 4.86, SD = 2.57) than during the control trials (M = 0.06, SD = 0.28) (t_{30} = 10.28, p < 0.001; d = 2.69 [95% CI: 1.59, 3.79]). Furthermore, the participants reported a higher expectation of a painful electrocutaneous stimulus during the threat trials (M = 4.91, SD = 2.12) than during the control trials (M = 0.07, SD = 0.40) (t_{30} = 12.63, p < 0.001; d = 3.10 [95% CI: 1.94, 4.25]). Finally, the participants rated the electrocutaneous stimuli as being moderately painful (M = 5.01, SD = 1.97).

3.2.2 PSS

The main effect of Cue was significant (F(1,29) = 17.44, p < 0.01), with threat trials (M = 13 ms, SD = 27) showing a larger PSS than the control trials (M = -1 ms, SD = 23) (d = 0.55 [95% CI: 0.27, 0.83]). There was no main effect of Location (F(1,29) = 1.25, p = 0.27) (d = 0.12 [95% CI: -0.08, 0.32]), meaning that, on average, the PSS was not different between the

near and far conditions (M = 4 ms, SD = 22, and M = 7 ms, SD = 27, respectively). Of particular interest, there was no significant interaction between Cue and Location ($F(1,29)$ = 0.005, p = 0.94) (d = 0.01 [95% CI: -0.34, 0.37]), indicating that the difference between the threat and control trials was similar in both the near and the far conditions (see Figure 4). All other main and interaction effects were non-significant (all $F < 1$)[2].

Insert Figure 4 about here

4. Discussion

We investigated how specific the spatial features of bodily threat are encoded in the attentional set. In the two experiments reported here, the participants made tactile TOJs for stimuli presented to the hands, while occasionally experiencing a painful stimulus. We manipulated the distance between the pain and the tactile stimulus locations (near versus far). In the first experiment, pain was expected either proximal to one of the tactile stimuli (on the hand) or more distant on the same body part (arm). In our second experiment, the painful stimulus was expected either proximal to one of the tactile stimuli (on the hand) or on a different body-part at the same body side (leg). The results revealed that, in the near condition of both experiments, the participants became aware of tactile stimuli presented to the "threatened" hand more quickly as compared to the "neutral" hand. Of particular interest, the data in the far condition in both experiments showed a similar prioritization effect when pain

[2] Independent t-tests indicated no significant differences in perceived intensity (per) of the *painful* stimuli between participants who received painful stimulation on the left (M_{hand} = 4.25 ± 2; M_{leg} = 4.56 ± 2.11) of right side (M_{hand} = 5.57 ± 1.95; M_{leg} = 5.60 ± 2.21) of the limb ($t_{perhandleft,\ perhandright}(30)$= -0.43 p = 0.67, $t_{perlegleft,\ perlegright}(28)$= -0.04 p = 0.97) nor in physical intensity (phy) of the *painful* stimuli between participants who received painful stimulation on the left (M_{hand} = 2.01mA ± 0.53; M_{leg} = 2.23 mA ± 0.72) of right side (M_{hand} = 1.74 mA ± 0.75; M_{leg} = 1.88 mA ± 0.98) of the limb ($t_{phyhandleft,\ phyhandright}(30)$= -0.98 p = 0.38, $t_{phylegleft,\ phylegright}(28)$= -0.46 p = 0.65). Furthermore, paired-sampled t-test indicated no significant differences in perceived intensity (per) and physical intensity (phy) of the *tactile* stimuli between the left and right hand ($t_{per}(30)$= -0.19 p = 0.85; $t_{phy}(30)$ = 1.02 p = 0.31). Moreover, no significant differences were found in physical as well as perceived intensity of the tactile stimuli between the left and right hand for participants who received painful stimulation on the left neither for participants who received painful stimulation on the right side of the limb ($t_{perpainleft}(16)$ = 0.18 p = 0.86; $t_{perpainright}(13)$ = -0.54 p = 0.60; $t_{phypainleft}(16)$ = 1.26 p = 0.23; $t_{phypainright}(13)$= -0.10 p = 0.92).

was expected at a different location of the same body part, as well as when pain was expected at a different body part at the same body side.

Our study replicates the findings of a previous experiment (Vanden Bulcke, et al., 2013) demonstrating that the anticipation of pain at one hand results in the prioritization of somatosensory sensations at that hand. Particularly intriguing in the case of the present study, and an important extension of the previous study, is our finding that the prioritization of tactile stimuli as a result of pain anticipation was not limited to the exact bodily location where pain was expected. More specifically, we found that prioritization also occurred when pain was expected at a different location on the same body part (arm) or at a different part of the body on the same body side (leg). The results of our studies suggest that the spatial features of bodily threat in our studies were not encoded in terms of the *exact* location where pain was anticipated, but in a more general manner, i.e., body part or even body side.

The paradigm proposed in this study may be useful to asses hypervigilance, i.e. a heightened attentional processing of painful and/or somatosensory information, in chronic pain patients. More precisely, hypervigilance is defined as a goal-dependent, attentional process that emerges when the threat value of pain is high, the fear system is activated, and the individual's current concern is to escape and avoid pain (Crombez et al., 2005). It is typically assumed to play an important role in pain perception and disability in chronic pain problems (Crombez, et al., 2005; Vlaeyen & Linton, 2000). Individuals who appraise bodily sensations as dangerous and who fear (re)injury, were thought to be more likely to scan the body for threatening sensations (Vlaeyen & Linton, 2000). Hence, we might generate interesting new hypotheses in this regard. For instance, it could be hypothesized that the fear of pain and re-injury often experienced by patients with musculoskeletal disorders will emerge as the attentional prioritization of the region of the body where they expect to feel

pain. We may further speculate that such prioritization may possibly exceed the exact pain relevant location and may extend to related bodily locations.

One can question whether anticipating pain not only involves a heightened attention to somatosensory sensations at those locations that are pain-relevant, but also leads to a perceptual amplification of bodily sensations. Several studies (Geisser et al., 2003; Hollins et al., 2009) have demonstrated that chronic pain patients show an increase in the perceived intensity of somatosensory stimulation although such perceptual amplification is not limited to the somatosensory modality. Note, however, that in those studies somatosensory perception was not specifically measured in pain-relevant bodily locations. Therefore, it could be questioned what role spatial location plays with regard to perceptual amplification. Interesting in this regard is the study by Van Ryckeghem et al. (2013). They instructed their participants to rate the intensity and the unpleasantness of somatosensory stimuli, after they had localized either a somatosensory or an auditory target at one particular location. Their results showed that the painful stimulus was experienced as less painful and less unpleasant when attending to an auditory target, particularly when pain was not at the attended spatial location.

Some issues should be considered when interpreting the results of the current study. First, as we made use of experimental pain to induce bodily threat in pain-free undergraduate students, one might ask to what extent the same process occurs in real life pain situations. It would certainly be interesting for future research to investigate this phenomenon in patients with unilateral pain problems, e.g., those suffering from unilateral knee pain. Based on the findings reported here, it might be expected that these patients would prioritize tactile sensations on the location where they expect to feel pain (e.g., knee) and on those bodily locations that are further away of the pain-relevant body location (e.g., tactile sensations presented on the ankles). Second, the more general encoding of the spatial features of bodily threat in the attentional set may also be the result of the response characteristics of the TOJ

task. Participants must encode targets on a left-right dimension ('left-side first' or 'right-side first'), which may have led to encoding of bodily threat in the attentional set in the same manner (on the left or right side of the body). One possible solution to address this issue would be conducting a similar TOJ task in which the response dimensions of the stimulus are orthogonal to the coding dimensions of bodily threat. A TOJ with four possible tactile locations (two on the left and two on the right hand, placed one above the other) is recommended in which participants have to indicate which one of two tactile stimuli administered to each hand, was presented first (the upper or the lower one) (Gallace, Soto-Faraco, Dalton, Kreukniet, & Spence, 2008). Another option would be to make use of a simultaneity judgment (SJ) task (Axelrod, Thompson, & Cohen, 1968; Zampini, Shore, & Spence, 2005), in which participants have to judge whether or not two tactile stimuli delivered to the left and right hand were presented simultaneous. In contrast to the TOJ task, participants do not need to compute the location of the tactile stimuli in order to judge whether or not they occur simultaneously. Third, it is important to note that our study paradigm does not allow for conclusions to be drawn about the effects of *actual* pain on tactile perception, and is only informative for the assessment of effects of *anticipated* pain on tactile processing. While the latter typically refers to cognitive mechanisms, the former rather refers to sensory interactions between pain and tactile stimuli, such as touch gating, the phenomenon that tactile thresholds are elevated by the concomitant presence of pain, especially when they are presented in close proximity (Bolanowski, Gescheider, Fontana, Niemiec, & Tromblay, 2001; Harper & Hollins, 2012). Fourth, we did not use a control condition in which a non-painful somatosensory stimulus at a specific location of the body was anticipated. Stimuli might become relevant in many other ways, which might also result in prioritized processing. As we only used painful stimuli, we cannot draw any conclusions about the specificity of our prioritization effect. However, it has previously been

demonstrated that visual cues signaling a painful stimulus attract more attention than visual cues signaling a non-painful tactile stimulus (e.g., Van Damme, Eccleston, & Crombez, 2004b; Van Damme, Eccleston, Crombez, &, Goubert, 2004c; Van Damme & Legrain, 2012). Although we assume that our effect is mainly due to the affective-motivational relevance of the pain stimulus, it is possible that part of the prioritization effect in our study is not unique to the anticipation of pain. It might have been mediated by other mechanisms (e.g. arousal) to some extent (Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008). Future studies should include an adequate control condition and may wish to investigate the role of potential mediating mechanisms. Fifth, one can argue that our studies are variant of the classic cueing effect (Posner, 1980). That is, when people expect a painful stimulus in one hemi-space, attention is oriented to that side of the body and facilitates the processing of somatosensory input occurring on the same half of the body. Here, cues might have triggered the painful location, which in turn might have resulted in the orientation of attention towards that threatened bodily location. As such, stimuli that are presented at that location will be facilitated. Finally, in the two experiments reported here, only two spatial locations were used to test the generalization of the prioritization effect. To draw conclusions about the specific boundaries of this effect, it would be interesting for further research to systematically vary several different graduations on a spatially-defined dimension.

In conclusion, we found that the anticipation of a painful stimulus results in the prioritization of somatosensory sensations in the region where individuals expect to feel pain. Furthermore, the results of our study also extend previous findings and suggest that the encoding of spatial features of bodily threat is not limited to the exact location where pain is anticipated. In our studies, the top-down prioritization of somatosensory sensations is generalized to the entire body part and even to different body parts at the same side of the body.

5. Acknowledgements

This study was supported by a Research Grant (3G005611) by the Research Foundation Flanders (FWO) awarded to S. Van Damme and G. Crombez. There are no conflicts of interest that may arise as a result of this research. We would like to thank Prof. dr. Lieven Danneels and Prof. dr. Armand De Clercq for helpful comments regarding the manuscript.

6. References

Arntz, A., Dreessen, L., & De Jong, P. (1994). The influence of anxiety on pain: attentional and atrributional mediators. *Pain, 56*, 307-314.

Axelrod, S., Thompson, L.W., & Cohen, L.D. (1968). Effects of senescence on the temporal resolution of somesthetic stimuli presented to one hand or both. *Journal of Gerontology, 23*, 191-195.

Bolanowski, S., Gescheider, G., Fontana, A., Niemiec, J., & Tromblay, J. (2001). The effects of heat-induced pain on the dectability, discriminability, and sensation magnitude of vibrotactile stimuli. *Somatosensory & Motor Research, 18*, 5-9.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. San Diego, CA: McGraw-Hill.

Crombez, G., Baeyens, F., & Eelen, P. (1994). Sensory and temporal information about impending pain: the influence of predictability of pain. *Behavioural Research Therapy, 32*, 611-622.

Crombez, G., Eccleston, C., Baeyens, F., & Eelen, P. (1998). When somatic information threatens, catastrophic thinking enhances attentional interference. *Pain, 75*, 187-198.

Crombez, G., Van Damme, S., & Eccleston, C. (2005). Hypervigilance to pain: an experimental and clinical analysis. *Pain, 116*, 4-7.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193-222.

Dowman, R. (2001). Attentional set effects on spinal and supraspinal responses to pain. *Psychophysiology, 38*, 341-464.

Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological Methods, 1*, 170-177.

Eccleston, C., & Crombez, G. (1999). Pain demands attention: a cognitive-affective model of the interruptive function of pain. *Psychological Bulletin, 125*, 356-366.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1030-1044.

Gallace, A., Soto-Faraco, S., Dalton, P., Kreukniet, B., & Spence, C. (2008). Response requirements modulate tactile spatial congruency effects. *Experimental Brain Research, 191*, 171-186.

Gallace, A., & Spence, C. (2014). *In touch with the future: The sense of touch from cognitive neuroscience to virtual reality*. Oxford: Oxford University Press.

Geisser, M.E., Casey, K.L., Bruckshu, C.B., Ribbens, C.M., Appleton, B.B., & Crofford, L.J. (2003). Perception of noxious and innocuous heat stimulation among healthy women and women with fibromyalgia: association with mood, somatic focus, and catastrophizing. *Pain, 102*, 243-250.

Harper, D. E., & Hollins, M. (2012). Is touch gating due to sensory or cognitive interference? *Pain, 153*, 1082-1090.

Hollins, M., Harper, D., Gallagher, S., Owings, E. W., Lim, P. F., Miller, V., Siddiqi, M. Q., & Maixner, W. (2009). Perceived intensity and unpleasantness of cutaneous and auditory stimuli: an evaluation of the generalized hypervigilance hypothesis. *Pain, 141*, 215-221.

Legrain, V., Mancini, F., Sambo, C. F., Torta, D. M., Ronga, I., & Valentini, E. (2012). Cognitive aspects of nociception and pain: bridging neurophysiology with cognitive psychology. *Neurophysiologie Clinique, 42*, 325-336.

Legrain, V., Van Damme, S., Eccleston, C., Davis, K. D., Seminowicz, D. A., & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain, 144*, 230-232.

Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *Journal of the Acoustical Society of America, 49*, 467-477.

McCracken, L. (1997). Attention to pain in persons with chronic pain: a behavioral approach. *Behavior Therapy, 28*, 271-284.

McGlone, F.P., Lloyd, D.M., & Tipper, S. (1999). Manipulation of attention within the somatosensory systems. In D. Harris (Ed.), *Engineering psychology and cognitive ergonomics, Vol. 4: Job design, product design and human-computer interaction* (pp. 309-315). Ashgate Publishing: Hampshire.

Piéron, H. (1952). *The sensations: Their functions, processes and mechanisms*. New Haven: Yale University Press.

Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

Roelofs, J., Peters, M., Muris, P., & Vlaeyen, J. (2002). Dutch version of the Pain Vigilance and Awareness Questionnaire: validity and reliability in a pain-free population. *Behaviour Research and Therapy, 40*, 1081-1090.

Shore, D., Gray, K., Spry, E., & Spence, C. (2005). Spatial modulation of tactile temporal-order judgments. *Perception, 34*, 1251-1262.

Spence, C., Shore, D., & Klein, R. (2001). Multisensory prior entry. *Journal of Experimental Psychology: General, 130*, 799-832.

Sullivan, M., Bischop, S., & Pivik, J. (1995). The Pain Catastrophizing Scale: Development and validation. *Psychological Assesment, 7*, 524-532.

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain, 96*, 319-324.

Van Damme, S., Crombez, G., & Eccleston, C. (2004a). Disengagement from pain: the role of catastrophic thinking about pain. *Pain, 107*, 70-76.

Van Damme S, Crombez G, Eccleston C. (2004b) The anticipation of pain modulates spatial attention: evidence for pain-specificity in high-pain catastrophizers. *Pain, 111*, 392-399.

Van Damme S, Crombez G, Eccleston C., & Goubert, L. (2004c). Impaired disengagement from threatening cues of impending pain in a crossmodal cueing paradigm. *European Journal of Pain, 8*, 227-236.

Van Damme, S., Gallace, A., Spence, C., Crombez, G., & Moseley, G. L. (2009). Does the sight of physical threat induce a tactile processing bias? Modality-specific attentional facilitation induced by viewing threatening pictures. *Brain Research, 1253*, 100-106.

Van Damme, S., & Legrain, V. (2012). How efficient is the orienting of spatial attention to pain? An experimental investigation. *Pain, 153*, 1226-1231.

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and Biobehavioral Reviews, 34*, 204-213.

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain, 154*, 1464-1468.

Van Ryckeghem, D.M.L., Crombez, G., Eccleston, C., Legrain, V., & Van Damme, S. (2013). Keeping pain out of our mind: the role of attentional set in pain. *European Journal of Pain, 17*, 402-411.

Vlaeyen, J.W.S., & Linton, S.J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: A state of the art. *Pain, 85*, 317-332.
Vogt, J., De Houwer, J., Koster, E.H.W., Van Damme, S., & Crombez, G. (2008). Allocation of spatial attention to emotional stimuli depends upon arousal and not valence. *Emotion, 8*, 880-885.
Weinstein, S. (1968). *Intensive and extensive aspects of tactile sensitivity as a function of body part, sex and laterality.* Springfield: Thomas.
Yantis, S. (2000). *Goal-directed and stimulus-driven determinants of attentional control*. Cambridge, MA: MIT Press.
Zampini, M., Bird, K. S., Bentley, D. E., Watson, A., Barrett, G., Jones, A. K., & Spence, C. (2007). 'Prior entry' for pain: Attention speeds the perceptual processing of painful stimuli. *Neuroscience Letters, 414*, 75-79.
Zampini, M., Shore, D. I., & Spence, C. (2005). Audiovisual prior entry. *Neuroscience Letters, 381*, 217-222.

6. Figures captions

Figure 1. Temporal order judgment (TOJ) data for Experiment 1. Average of the fitted data for all participants. Data are plotted as a proportion of responses that coincided with the side on which the threatening stimuli were presented (y-axis), as a function of stimulus onset asynchrony (SOA, x-axis).The different conditions are represented by different symbols and line styles (see legend).

Figure 2. Index for attentional prioritization (PSS) of the threatened hand and arm (in ms and with standard errors) in control and threat trials. Positive values indicate that stimuli on the threatened hand were perceived more rapidly than those presented to the other hand, whereas negative values indicate that stimuli on the neutral hand were perceived more rapidly than those presented to the threatened hand (* $p < 0.05$).

Figure 3. Temporal order judgment (TOJ) data for Experiment 2. Average of the fitted data for all participants. Data are plotted as a proportion of responses that coincided with the side on which the threatening stimuli were presented (y-axis), as a function of stimulus onset asynchrony (SOA, x-axis).The different conditions are represented by different symbols and line styles (see legend).

Figure 4. Index for attentional prioritization (PSS) of the threatened hand and leg (in ms and with standard errors) in control and threat trials. Positive values indicate that stimuli on the threatened hand are perceived more rapidly than those presented to the other hand, whereas negative values indicate that stimuli on the neutral hand are perceived more rapidly than those presented to the threatened hand (** $p < 0.01$).

Figure 1

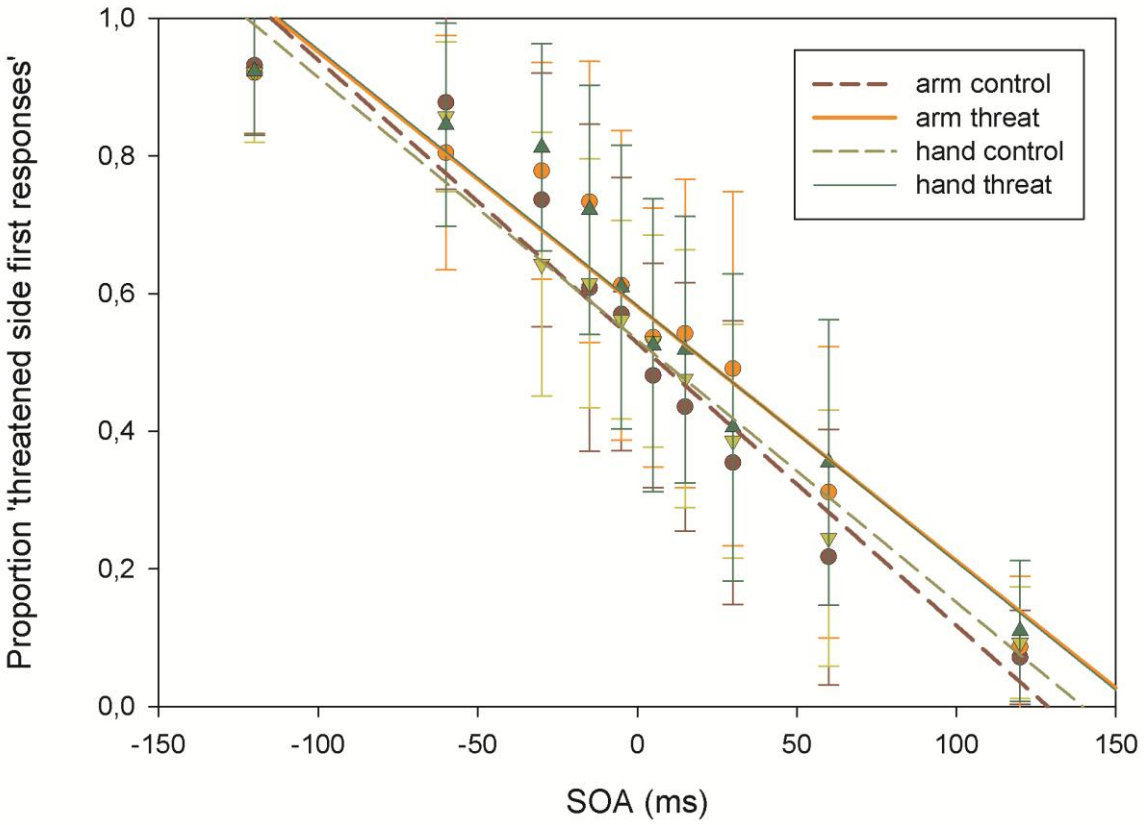
Proportion 'threatened side first responses'
1,0
0,8
0,6
0,4
0,2
0,0
-150
-100
-50
0
50
100
150
SOA (ms)
arm control
arm threat
hand control
hand threat

Figure 2

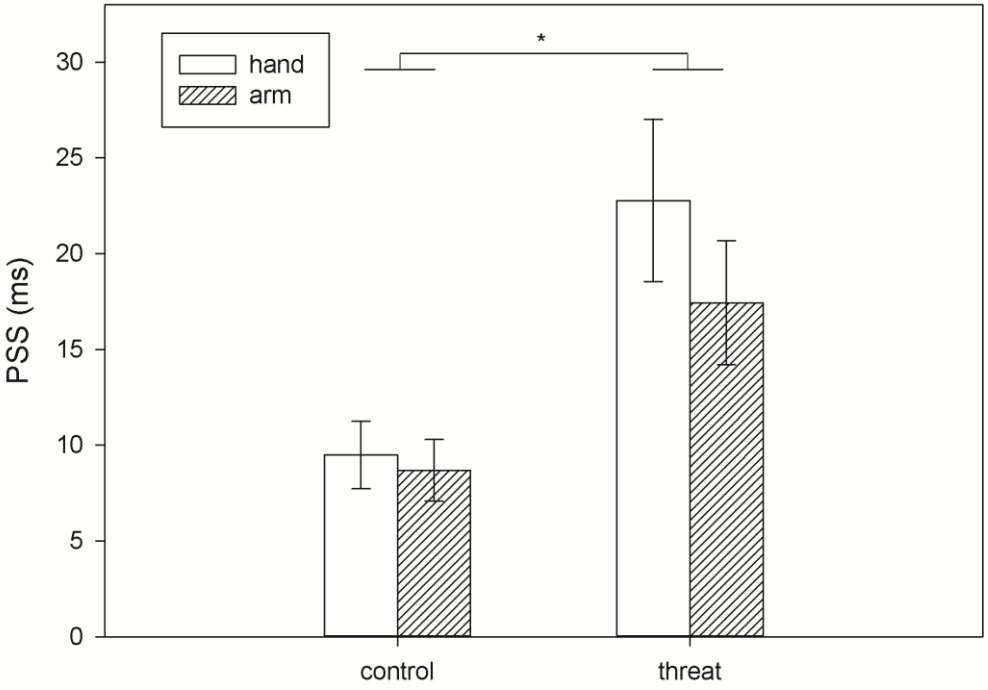

Figure 3

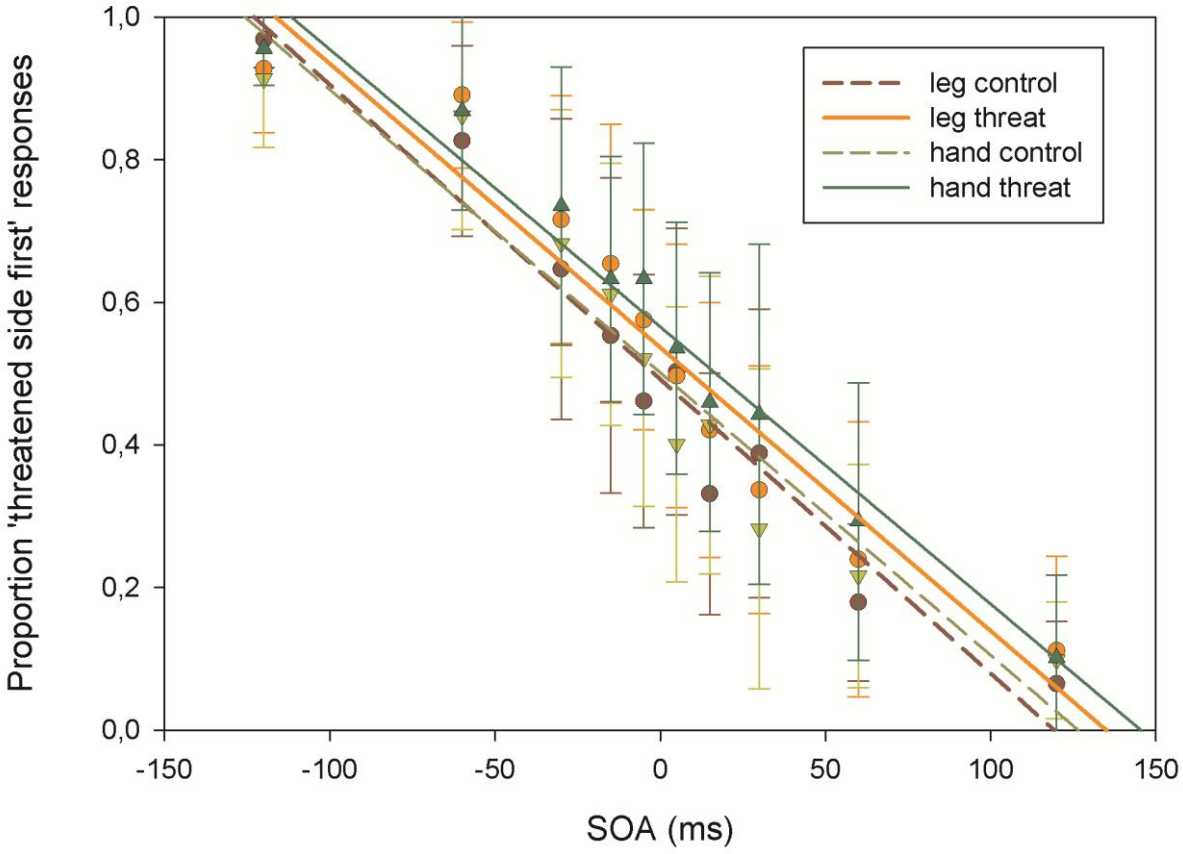
Proportion 'threatened side first' responses
1,0
0,8
0,6
0,4
0,2
0,0
-150
-100
-50
0
50
100
150
SOA (ms)
leg control
leg threat
hand control
hand threat

Figure 4