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Distorted distance perception to reachable points in people with chronic shoulder pain

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ABSTRACT

Perception is not simply a carbon copy of the real world, but is subject to distortions that may reflect protective drive. This study aimed to investigate whether people with chronic shoulder pain show perceptual distortions of space and body that may promote protective behavior. Eighty-four people with shoulder pain and 51 healthy controls participated. Participants estimated (1) distances to points on a cork-board within and outside reaching distance, and (2) the perceived length of their own arms. A novel measure of movement-related pain was also used to determine whether movement-related pain relates to perceptual distortion. Overall, distance and arm length estimates did not differ between groups, nor did participants perceive their arms to be of different length. However, a moderate correlation between movement-related pain and the index of distance perception was found within the pain group, specifically for distance estimates to points within reach. Our results suggest that distorted perception is not a typical consequence of chronic shoulder pain; however, that it may occur in cases where pain is strongly linked to movement. Our findings have implications for understanding avoidance of movement in people with persistent pain.

1. Introduction

Perception has evolved to optimise action, rather than to perfectly represent reality (Hoffman and Singh, 2012; Clark, 2013). Since the physiological state of the body and the environment around us are constantly changing over time, perception may work as an adaptive interface to facilitate selection of behaviors that favor survival (Williams et al., 2012; Hoffman et al., 2015).

Famously, people are known to over-estimate the gradient of terrain during periods of fatigue, when under load, or when in poor physical condition (Proffit, 2006). This equates to a scaling of spatial perception in accordance with bodily state - an example of what is posited by the economy of action hypothesis (Proffit, 2006). Some researchers have proposed that when people are in pain, spatial perceptual distortions may occur to promote safety behaviors, such as avoidance of movement (Tabor et al. 2013, 2016), although research on this idea is scarce and results mixed. Understanding altered spatial perception in people with pain could assist in understanding avoidance behaviors that may contribute to ongoing dysfunction (Vlaeyen et al., 2016).

Following shoulder injury, adaptations to spatial perception that make objects seem to be further away, may initially be advantageous in discouraging movement and promoting rest. In the long term, however, adaptations that continue to discourage movement may contribute to a cycle of disuse and disability. In this study, we aimed (1) to compare distance perception within and beyond reaching distance between people with and without shoulder pain; (2) to compare perceived length of the painful limb relative to the non-painful limb and to the control group; and (3) to investigate whether spatial distortion is correlated with the strength of the relationship between pain and movement. We hypothesized that in people with shoulder pain (1) points within and outside reach would appear more distant; (2) that the perceived size of the painful limb would be reduced relative to the pain-free arm and to

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controls, and (3) that spatial distortions would correlate with the degree that pain is related to movement.

2. Materials and methods

2.1. Participants

A convenience sample of 84 people with shoulder pain (60.7% female, mean age 65 ± 9.4 years old) and 51 healthy volunteers (68.62% female, mean age 57 ± 11.52 years old) participated. A preliminary analysis using G*POWER showed that these sample sizes would be required in order to guarantee 80% of power in the primary statistical analysis. Participants with shoulder pain were consecutively selected from the Shoulder and Elbow Group at the Orthopedic Institute of the Clinical Hospital of São Paulo.

Participants were eligible for the shoulder pain group if they were: right-handed, symptomatic in their dominant shoulder, sedentary for the preceding six months and had shoulder pain for at least the preceding three months. Potential participants were examined by a physician to exclude shoulder complaints resulting from cervical spine dysfunction. Cognitive deficits, use of medications for pain control in the preceding 24 h, neurological diseases, signs of adhesive capsulitis (limited passive range of shoulder motion: external rotation < 30°; elevation < 150°), previous shoulder surgery, and rheumatic diseases were used as additional exclusion criteria.

Pain-free participants were included in the control group (CG). A history of pain lasting more than three months or pain present at the time of testing were used as exclusion criteria.

2.2. Assessments

Sociodemographic data were recorded on a questionnaire and handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971).

2.2.1. Procedure and apparatus for the distance estimates

Participants used a ratio judgment to estimate the distance between their index finger and nine evenly spaced points on a cork-board. To standardize the position, participants stood facing the cork-board, with their right limb supported in a neutral position with the elbow flexed to 90° and index finger extended. The sternum was aligned with the center of the cork-board, and the height of the board was adjusted such that the subject's elevated arm would point directly at the central point with 90° of shoulder flexion. Depending on the stage of the test, participants were moved such that their index finger was exactly 45 cm or 100 cm from the central point (see Fig. 1).

To introduce the concept of a ratio judgment for distance estimates, all participants performed an initial task in which they were asked to judge the length of a series of lines in proportion to a 5 cm reference line that was always visible. The participants made 10 judgments and the only instruction they had was to use the 5 cm line as a length reference. That is, if they perceived the distance to be equivalent to 4 times the 5 cm reference line, they would estimate the distance as 20 cm. No performance feedback was given during this initial task.

Next, participants were instructed to estimate the distance from the index finger of the dominant hand to each of the nine points in a pseudo-random order.

2.2.2. Pain measurement

Movement-related pain was assessed using another ratio judgment method known as the numeric magnitude estimation procedure (Stevens, 1957, 1958b, 1959, 1960; Stevens, 1958a). The participants were instructed to reach toward the central point of the cork-board, and to consider the associated pain to be of a magnitude of 100 (Alaiti et al., under review a, b). Next, participants reached to each of the remaining points and rated their pain relative the 100 point reference. For example, if reaching to a given point evoked twice the pain of the reference movement, they would rate that pain as 200. The assessment of movement-related pain were made prior to the distance judgments in order to systematize the pain reference that subjects would use to make the estimates. If no pain occurred when reaching to the central point, the test proceeded until a painful movement was experienced. In this way, the first experienced pain formed the 100-point reference value for subsequent ratio judgments. If no movements were painful, the score remained 0.

Fig. 1. Participant positioning during the distance judgement task.

2.2.3. Arm length judgment

Following the distance judgments, participants estimated the lengths of their arms. To do this, participants were first shown a 30 cm measuring tape as a length reference. The experimenter then touched the participant's right acromion and the tip of the index finger to clarify the anatomical reference points for the subsequent task. Next, the participant raised their right arm to 90° of shoulder flexion with their eyes closed, and were asked to verbalize the perceived length of the right arm. Finally, the participant raised both arms to 90° of shoulder flexion, stated whether they perceived a difference between the size of the two arms (yes/no), and then judged the size of the left arm. Participants were asked if there was a perceived difference first, in order to discourage them from simply reciting the initial estimate.

2.3. Statistical analysis

The statistical analysis was performed using Statistica (v.10, StatSoft, Inc., Tulsa, USA).

Because participants had not been randomly allocated to the groups, a logistic regression analysis was conducted to identify if there was any baseline demographic difference between the groups. Firstly, a univariate logistic regression was used to verify each variable. If one of the variables reached the criterion significance level ($p < 0.2$) a multivariate analyses was to be conducted to further examine interactions between the variables. The analyses were considered statically significant if $p < 0.05$.

The pain ratings corresponding to reaching to the nine spatial points were used to generate an index that expressed the relationship between

pain and movement. We have previously tested and validated this method in people with chronic shoulder pain (Alaiti et al., under review a, b). This index was constructed according to the mathematical model of Stevens's Power Law (Stevens, 1957, 1958b, 1959, 1960; Stevens, 1958a): the pain ratings for the nine movements were first ordered from lowest to highest and then plotted in a power function in order to generate the exponent of the Power Function Law, that will henceforth be referred to as the index of movement-related pain (IMRP).

According to this mathematical model, individuals with a greater number of painful movements and a lower variability of pain will produce lower exponents, while individuals with fewer painful movements, and/or a greater variability of pain across movements, will produce higher exponents. Practically speaking, if an individual's pain hardly varies between different movements, the IMRP will be lower. On the other hand, if an individual reports low levels of pain when reaching to the lower points, but high levels of pain when reaching to the higher points, then they will have a higher IMRP. Thus, the extent to which movement and pain are related can be indexed using the IMRP in a way that is not possible using a simple Visual Analogue Scale.

In order to quantify the overall accuracy of the distance judgments made from 45 cm to 100 cm, we used a mathematical model similar to that used for the relationship between pain ratings and movements to generate an 'index of distortion'. However, in this case the distance estimates were not ordered in an increasing way but were derived by plotting the real distances on the y-axis against the estimates on the x-axis to form a power function in which an exponent of 1 is the most accurate judgment possible. In other words, the closer this index is to 1, the more precise was the judgment. Judgments that were over- or under-estimated would produce numbers greater or less than one, respectively.

The arm size judgments were analyzed by means of two measures. First, an index of perceptual distortion was calculated for the affected arm by dividing the estimated arm size by the actual arm size (from the tip of the index finger to the acromion). Second, the index of perceptual distortion of the affected arm was divided by the index for the healthy arm.

2.3.1. Primary analyses: between-group effects

To test the hypothesis that people with chronic shoulder pain would perceive spatial points as more distant, a one-way ANOVA was conducted using the IMPR at 45 cm and 100 cm as the dependent variable. The Bartlett test of homogeneity of variances was used prior to the ANOVA to test whether a correction should be used.

To test the hypothesis that people with chronic shoulder pain would perceive their affected limb as shorter than their non-painful limb, two independent student t-tests were conducted to test for differences in perceived arm length ('index of distortion') (1) between arms, in the pain group only, and (2) between groups.

2.3.2. Secondary analyses: within-group effects

To test the hypothesis that spatial distortions would correlate with the strength of the relationship between pain and movement, we performed two two-sided Spearman Rank Order correlation analyses between (1) the IMRP and distance estimates, and (2) the IMRP and estimates of upper limb length. Only data from the shoulder pain group were used for these analyses. This non-parametric test was chosen because visual analysis of histogram plots suggested that the data were not normally distributed.

3. Results

3.1. Group characteristics

The logistic regression analysis confirmed that groups were not statistically different at baseline with respect to demographic data. Participant characteristics are presented in Table 1.

Table 1
Group's characteristics.

Variables	Shoulder pain	No pain	p
N	84	51	–
Age	65 ± 9.4	57 ± 11.52	0.2
Sex	60.7% females	68.62% females	0.15
Years of Study	6.76 ± 3.77	9.27 ± 4.9	0.09
Duration of Symptoms	90.61 ± 78.4	0	–
ELD	1 ± 0.19	1 ± 0.16	–
EDP45	1.24 ± 0.55	1.08 ± 0.64	–
EDP100	1.51 ± 0.94	1.71 ± 1,12	–
IMRP	2.21 ± 2.17	0	–
IDPA	1 ± 0.38	1 ± 0.22	–
IDBA	0.99 ± 0.12	0.98 ± 0.07	–

The values represent the mean ± SD unless otherwise indicated. Abbreviations: Duration of Symptoms in months; ELD, exponent of line distortion; EDPs, exponent of distance perception; IMRP, index of movement-related pain; IDPA, index of distortion of the painful arm; RDBA, index of distortion between the arms.

3.2. Primary analyses: between-group effects

One-way ANOVA showed no statistically significant difference between the groups in estimates of the distance to the spatial points ($F(1,132) = 1.28$, $p = 0.259$). Likewise, student t-tests showed no statistically significant difference in perception of arm length between groups ($t[120.15] = 0.4$, $p = 0.68$) or between sides ($t[132.84] = 0.48 = p = 0.62$).

3.3. Secondary analyses: within-group effects

In the group with shoulder pain, the index of movement-related pain had no correlation with the index of distortion of the painful arm (Spearman's rho = 0.13, p = 0.22) and the index of distortion between arms (Spearman's rho = 0.05, p = 0.65), but a moderate correlation was found with the index of distance perception (Spearman's rho = 0.30, p = 0.011). Notably, this correlation was found only at the standing distance of 45 cm away, and was non-significant at the 100 cm distance (Spearman's rho = 0.10, p = 0.11).

4. Discussion

In this study, we aimed to compare distance perception between people with and without shoulder pain, to compare the perceived length of the painful limb relative to the non-painful limb and relative to the control group, and to investigate whether spatial distortion is related to the strength of the relationship between pain and movement. We hypothesized that in people with shoulder pain, points within and outside reach would seem further away, the perceived length of the painful limb would be reduced relative to the pain-free arm and to controls, and spatial distortions would correlate with the strength of the relationship between pain and movement.

The hypothesis that points within and outside reaching distance would appear more distant was not upheld, in that no overall group differences were found for any index of distance perception. The hypothesis that perceived size of the painful limb would be reduced was also not upheld, in that no side or group differences were found. In contrast, the hypothesis that spatial distortions would be more pronounced in people who showed a strong relationship between pain and movement was supported, in that the index of spatial distortion showed a moderate positive correlation with the index of movement-related pain. This suggests that individuals with strongly movement-linked pain tended to overestimate the distance to spatial points. Notably, this relationship was only significant at the 45 cm distance from the board containing the spatial points, and not at the 100 cm distance. This may

indicate that this perceptual distortion is specific to distances to objects that are located within reach.

4.1. Implications

Our results clearly show that distorted perception is not a universal consequence of having shoulder pain. Rather, our results suggest that perception may be distorted in some patients, depending on at least two factors. First, distortion may depend on the behavioral relevance of the target in question. That is, a given distance may be more likely to be overestimated if it is possible to reach to that distance. This suggestion seems plausible, but would need to be verified in future studies that directly manipulate behavioral relevance. Second, distortions may occur only in perceptual domains that are linked to, or can predict, painful interactions. Conversely, when movement is not linked to pain, as in those participants with low IMRP, spatial distortion does not occur.

In contrast to what has previously been shown for pain in other body regions (Moseley et al., 2012; Gilpin et al., 2015), we did not find distortions in the perceived length of the symptomatic upper limb relative to the unaffected arm and to pain-free controls. This may relate to the nature of the painful conditions studied, which may involve altered sensory perception to differing degrees.

That the perception of the external environment might be influenced by bodily state is consistent with the economy of action hypothesis. This theory suggests that conscious perception is an inference that can be optimized to serve protection and energy efficiency. The theory has previously been explored in other domains (Proffit, 2006; Witt et al., 2004; Tabor et al., 2013, 2015, 2016). Interestingly, previous experimentation in clinical populations has so far failed to support theoretical predictions of the economy of action hypothesis in people with persistent pain. Tabor et al. (2016) asked people to estimate distance to a series of target cones to which they were to walk. Participants with various chronic pain conditions were found to estimate the distances similarly to their pain-free peers. Critically, in the current study, participants made judgments about the distances to the spatial points without the intention to interact with those points. That the current study found spatial distortions when measuring judgments towards inert spatial points, suggests that distortions might be present prior to the intention to act.

The current findings are relevant to understanding perception-related clinical complaints and the processes that underlie avoidance behaviors in some patients with chronic shoulder pain. Previous studies have demonstrated that avoidance is a major component in subjects with chronic pain (Vlaeyen and Linton, 2012) and a number of mechanisms may contribute to it, such as catastrophizing beliefs (Vlaeyen et al., 2016), classically conditioned fear (Meulders et al., 2016), operant conditioning (Meulders et al., 2016) and vicarious learning (Goubert et al., 2011). Altered spatial perception may also play some role in the perpetuation of avoidance behaviors, although our data suggests this might be limited.

Besides that, uncommon verbal reports about subjective sensations may occasionally occur in clinical practice, such as abnormal body sensations in patients with fibromyalgia (Martínez et al., 2018). Knowledge of these processes may help clinicians to reassure their patients during the rehabilitation process, thus deconstructing potentially confusing beliefs about perception-related clinical complaints that may incite fear and anxiety about their clinical condition.

4.2. Limitations

The current study has several limitations. Most notably, the cross-sectional nature of this study does not allow us to test for causative relationships between movement-related pain, perceptual distortions and avoidance behaviors in subjects with chronic pain complaints. Further, we can only posit the possible mechanisms underlying our results. Finally, the lack of between-group effect for the primary analysis reduces our confidence when inferring meaning from the secondary analysis and, as such, some caution is required when drawing conclusions.

5. Conclusion

In this study, we aimed to investigate the accuracy of distance perception between the painful arm and points within and outside reaching distance, in people with chronic shoulder pain. Further, we aimed to investigate whether the extent of spatial distortion is dependent on how strongly movement and pain are related. Our hypothesis that people with chronic shoulder pain would show distorted spatial perception relative to controls was not supported. However, within the patient group, spatial distortions did correlate with the strength of the relationship between pain and movement, suggesting that spatial distortions may occur when pain is strongly linked to movement. Notably, this relationship was only significant when estimating the distance to points within reaching distance, suggesting that perceptual distortions depend on behavioral relevance. These findings may assist in understanding the mechanisms underlying phenomena such as avoidance behaviors and learned non-use behaviors in some patients with persistent shoulder pain.

Conflicts of interest

This study was approved by the Ethics Committee on Human Research of the Psychology Institute of the University of São Paulo and follows the statements of the Declaration of Helsinki. Conflicts of Interest: There are no conflicts of interest.

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