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Perceptual inference in chronic pain: An investigation into the Economy of Action hypothesis

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Abstract

Objective

The experience of chronic pain critically alters one's ability to interact with their environment. One fundamental issue that has received little attention however, is whether chronic pain disrupts how one perceives their environment in the first place. The Economy of Action hypothesis purports that the environment is spatially scaled according to the ability of the observer. Under this hypothesis it has been proposed that the perception of the world is different between those with and without chronic pain. Such a possibility has profound implications for the investigation and treatment of pain. The present investigation looked to test the application of this hypothesis to a heterogeneous chronic pain population.

Methods

Chronic pain sufferers (36; 27F) and matched pain-free controls were recruited. Each participant was required to judge the distance to a series of target cones, to which they were to subsequently walk. In addition, at each distance, participants used numerical rating scales to indicate their perceived effort and perceived pain associated with the distance presented.

Results

Our findings do not support the Economy of Action hypothesis: there were no significant differences in distance estimates between the chronic pain group and pain-free controls ($F(1,60)=0.927$; $p=0.340$). In addition, we found no predictive relationship in the chronic pain group between anticipated pain and estimated distance ($F(1,154)=0.122$, $p=0.727$), nor anticipated effort =1.171, $p= 0.281$) and estimated distance ($F(1,154)=1.171$, $p= 0.281$).

Discussion

The application of the Economy of Action hypothesis and the notion of spatial perceptual scaling as a means to assess and treat the experience of chronic pain are unfounded.

Key words

Economy of Action Hypothesis; distance perception; spatial scaling; Bayesian inference

1. Introduction

The experience of pain is inherently costly - it guides our behaviour and predictions, thereby minimising our encounters with future injury or pain. However, the costs and rewards associated with pain are dynamic, depending on the state of the individual and the context of the situation [1, 2]. Importantly, pain is an experience that incorporates both cognitive and sensory components, associated with altered cognitive processing [3, 4], altered perception of self [5-7], and altered behavior [8]. Protective behaviour is considered adaptive during acute pain but maladaptive in the context of chronic pain, because the tissue is presumed to have healed, rendering protective behaviour futile. However, we argue that pain, whether acute or chronic, is always rational, according to the suite of information available to the person [9, 10]. This perspective is congruent with the Bayesian inference framework [11-13], which emphasises the importance of understanding how information about the world, both internal and external, is integrated in the formation of perceptual experience [14, 15]. The method of information integration in perception has been the source of prolific research in the last decade [13, 16, 17], asserting that 'top-down' effects alter the processing of 'bottom-up' information [18]. One hypothesis, framed under the Economy of Action hypothesis, is that our spatial perceptions are scaled in a way that reflects the ability and the purpose of the perceiver [19-21]. Indeed, Witt et al, 2009, proposed that people who experience pain when they walk overestimate the distance to a target, in comparison to pain-free controls [22]. This opens up the exciting possibility that pain, an experience that is altered in relation to incoming information [2, 23], could in fact change the way incoming information is perceived in the first instance. However, the Economy of Action hypothesis has also been criticised on the grounds that the results of such studies likely reflect the influence of experimental biases rather than true ‘top-down’ effects on perception [24-26].

In order to clarify the influence that the experience of pain has on spatial perception, we interrogated the Economy of Action hypothesis in the context of heterogeneous chronic pain. First, we looked to establish whether chronic pain sufferers differ from pain-free controls in their attribution of effort to a walking task. Next we considered whether the experience of chronic pain is associated with an alteration in the perception of distance to a target to which one has to walk. Finally, we investigated whether pain and the appraisal of effort predicts an overestimation of distance in patients who suffer from chronic pain.

If the Economy of Action hypothesis is correct, then we would expect to observe a comparative overestimation of distance related to an increased effort appraisal in the chronic pain group, as compared to pain-free participants. However, if the hypothesis is not correct, then we would see no significant difference of spatial distance estimation between our two groups.

2. Methods

2.1 Participants

36 patients (27F) diagnosed with a chronic pain condition were recruited at a pain management centre (INPUT Pain Management) at St Thomas’ Hospital; 36 pain-free controls (28F) were recruited on the same hospital site. The profiles of all participants are reported in Table 1. The requisite sample size, to ensure 80% power to detect the effect with a critical **α of 0.05,** was determined using G*Power [27], based on previous findings indicating a likely medium effect size; data collection stopped when this number was satisfied. All participants volunteered for the study and gave informed consent. The experimental protocol was approved by the National Institute

for Social Care and Health Research (NISCHR), Research Ethics Service (IRAS project ID: 138710) and St Thomas' Hospital Research and Development services.

2.2 Materials and Apparatus

The experiment took place in a private, open-air environment at St Thomas' Hospital, London. Distance references that could be attained from the pathway were removed prior to testing. An orange traffic cone was used to mark the target distances.

2.3 Recruitment

Chronic pain patients were informed of the research study on the first day of their residential pain management programme. It was then left to the patients to approach the experimenter on Day 2 of their programme should they wish to take part in the study. Pain-free controls were recruited on the hospital site via posters. The first point of contact for all participants was with an impartial healthcare professional not associated with St Thomas' Hospital or INPUT pain management. After informed consent was granted, the experimenter walked with the participants to the start of the testing area.

2.4 Distance Estimation Task

2.4.1 Prior Information

While stationary, at the pre-marked start of the pathway, the experimenter explained that a cone would be placed once, randomly at five different distances (4m, 5m, 7m, 9m, 13m away from the participant) and that the participant would be required to estimate, to the nearest 10cm, how far away they thought the cone was from them for each distance. It was emphasized that the accuracy of their estimate was the key element of the task. They were then shown a 10cm measure, which was removed prior to the first estimation. Participants were then told that at each distance there was a 50% chance that they would be required to walk to the cone.

2.4.2 Initial Measures

Prior to starting the distance estimation task, participants completed the 6-item State Trait Anxiety Index [28], and were asked 'What is your current pain level?', participants verbally responded using an 11-point Numerical Rating Scale (NRS), anchored at the lowest level with 0 = "no pain" and at the highest level with 10 = "worst possible pain" (see Table 1. "Pain prior").

2.4.3 Procedure

The experimenter placed the cone at five predetermined distances in a pseudo-randomised, counterbalanced order; the distances were marked with tape that the participant was unable to see. It was explained that after each distance estimation, the experimenter would ask the participant to report two measures on a 11-point NRS. First, the anticipated pain level that the participant would experience during a required walk to the specified distance (Table 1. "Pain during"). The pain scale was anchored at the lowest level with 0 = "no pain" and at the highest level with 10 = "worst possible pain". Second, the anticipated effort that the participant would have to expend should they have to walk that distance. The effort scale was anchored at the lowest level with 0 = "no effort" and at the highest level with 10 = "greatest amount of effort imaginable".

3. Statistical Analysis

All analyses were conducted using PASW Statistics (v18.0.0, IBM Corporation, New York, USA). Initially, a repeated measures two (Factor=Group: Pain or No Pain) x five (Factor=Target Position: 1-5) ANOVA was performed on anticipated effort; followed by a second repeated measures two (Group- Pain or No Pain) x five (Factor=Target Position: 1-5) ANOVA performed on perceived distance. Secondary (exploratory) analyses were undertaken to explore the effects within the PAIN group.

First, a two (Factor=Anticipation Group: Pain anticipation or No pain anticipation) x five (Factor=Target Position: 1-5) ANOVA was performed on perceived distance. Secondly, three regression analyses were performed: 1. Anticipated Effort x Target Position; 2. Anticipated Pain x Target Position; 3. Difference in Anticipated pain x Target Position. For completeness, a fourth regression analysis was performed in the control group: Anticipated Effort x Target Position. If the data did not meet the assumptions of parametric statistics, the equivalent non-parametric tests were used. Significance of all statistical tests was set at $\alpha = 0.05$.

Anticipated location of Table 1

4. Results

The data from 10 participants (5 Patients; 5 Controls) were excluded from analyses due to variable units of distance being adopted by the participants. The remaining data (31 Patients; 31 Controls) were analysed. Distance estimations were standardised by converting the estimates into proportions (Distance Estimate/Actual Distance).

4.1 Primary analysis:

4.1.1 ANOVA 1 – testing whether anticipated effort differed between groups.

A significant effect of group (F (1,60)=69.486; p<0.001; η_p^2=0.54), a significant effect of effort (F (4,240)=14.987; p<0.001; η_p^2=0.20), and a significant effort*group interaction (F (4,240)=8.623; p<0.001; η_p^2=0.17) was found. That is, patients attributed significantly higher verbal effort scores over the 5 distances, with effort attribution increasing as distance increased, when compared to the pain-free controls (Fig. 1).

Anticipated location of Figure 1

4.1.2 ANOVA 2 – testing whether estimated distance to a target differed between groups.

We found no significant effect of group (*F*(1,60)=0.927; p=0.340), no significant effect of distance (*F*(4,240)=0.138; p=0.968), and no significant distance*group interaction (*F*(4,240)=0.125; p=0.973). That is, the distance estimations of people with chronic pain did not significantly differ from the distance estimations of pain-free controls. However, visual analysis (see Fig. 2) and standard deviation for the total mean proportional estimates indicated that patients with chronic pain (0.97 ±0.35) were more variable in their distance estimates than pain-free controls (0.91 ±0.183), particularly for shorter distances.

Anticipated location of Figure 2

4.2 Secondary Analysis:

4.2.1 ANOVA 3 - testing whether estimated distance to a target differed between those patients who anticipated the walk would increase their pain (n= 12) and those patients who did not (n= 19); (Group 1. Pain anticipation; Group 2. No Pain anticipation).

We found no significant effects of group (*F*(1,29)=0.398; p=0.533), distance (*F*(4,116)=0.033; p=0.998) nor distance*group interaction (*F*(4,116)=1.242; p=0.297). Within the group of people experiencing chronic pain we found no difference in distance estimations between those who anticipated an increase in pain if they were to walk to a target and those who anticipated no increase in pain if they were to walk to the target.

4.2.2 Regression- testing whether anticipated pain or anticipated effort predicted estimation of distance to a target, within the chronic pain group.

A linear regression established that, in the chronic pain group, neither anticipated pain (*F*(1,154)=0.122, p=0.727, see Fig. 3i & iii) nor anticipated effort (*F*(1,154)=1.171, p= 0.281, see Fig. 3ii) related to the estimations of distance (Fig. 3). For completeness, it was established that in the pain-free control group anticipated effort was not related to the estimations of distance ($F(1,154)= 0.398$, $p=0.529$, see Fig. 3iv).

Anticipated location of Figure 3

5. Discussion

We interrogated the Economy of Action hypothesis in a group of heterogeneous chronic pain sufferers and matched pain-free controls. Our results confirm that patients suffering from chronic pain rate the effort required to walk to a series of cones as significantly greater than pain-free controls do. This intuitively sensible result allowed us to pursue our primary aim: to determine whether the experience of chronic pain, a state associated with increased effort attribution, is associated with an alteration in the perceived distance to a target to which one has to walk. Our findings determined that there was no significant difference in distance estimates between a heterogeneous chronic pain group and a group of pain-free controls. Thus, our results do not support the notion that people who experience chronic pain perceive distance differently to those who are not experiencing pain and are thus not supportive of the Economy of Action Hypothesis [19-22, 29, 30].

We also considered whether differences existed within the heterogeneous pain group that help explain the greater variability in their distance estimates. Specifically, we compared patients who anticipated an increase in pain associated with walking to the target, with those who anticipated no increase in pain. This comparison was undertaken to further decipher the effect of the experience of pain on the perception of distance, comparing a group with an overall presence of pain irrespective of the nature of the task, with a group who specifically asserted an increase in pain associated with the task. We found that there was no difference in distance estimates between these two groups, which suggests that even when the task was considered inherently costly, in this case increasing the individual's pain level, the perception of distance was not effected.

Lastly, we looked to determine whether individual cost, in the form of the experience of pain or the attribution of effort to a task, alters the spatial scaling of distance to a target. The final level of analysis looked at whether anticipated pain or effort on walking predicted distance estimates to a target. We found that neither measure significantly predicted the distance estimates within our group of chronic pain patients (Fig. 3i-iii).

Our study reflects a comprehensive interrogation of the Economy of Action hypothesis, which predicts that visual spatial perceptions are scaled with respect to the current ability and the purpose of the perceiver. For example, hills are described as looking steeper to the encumbered walker [20], heights looking higher to the fearful climber [31]; and those who experience pain on walking perceive report the walking target as further away than pain-free individuals do [22]. Criticisms of such work include methodological limitations [24], which our design largely removed. Thus, the lack of effects observed here cast doubt over the hypothesis insofar as it is applied to the relationship between the state of the observer (pain/pain-free) and the alteration of the scaling of the spatial perception of distance. That we used a heterogeneous pain group as opposed to a homogenous low back pain group [22], may be relevant to the contrasting results, however, importantly our results show that neither the general presence of pain, nor the specific anticipation of an increase in pain on walking, result in an overestimation of distance.

The interaction between 'top-down' and 'bottom-up' information processing has been long debated [18, 32-34] ranging from the position that describes vision as an encapsulated process [32] to the notion that vision is continually influenced by cognitive information [33, 35]. Relevant to this discussion and to the present study, the influence of ‘top-down’ effects in relation to spatial perception has recently been dismissed as fallacy, citing judgment and memory effects as the true perpetrators of altered perception in experimental investigations of the issue [24]. Superficially, our results proffer ‘support for the negative’, by failing to detect ‘top-down’ influences on perception based on the state of the observer.

In light of theoretical and practical evidence however, we caution against generalising these results too broadly. Using an implicit learning paradigm, Kok and colleagues demonstrated that prior knowledge alters the way that visual information is processed at the earliest stages of vision [36]. Their work adds neural evidence to support the ‘top-down’ effects demonstrated in perceptual illusions such as the ‘light from above’ [37], the Müller-Lyer, as well as the Ponzo and Hering illusions [18, 33]. As such, the extent to which ‘top-down’ effects could influence the perception of one’s environment, outside of the scope of the Economy of Action hypothesis and spatial scaling, is still open to clarification.

Our results show that although people in pain do not perceive their world differently from a quantitative scale perspective, they do attribute significantly more effort to tasks in their environment than people without pain attribute. Although this represents an intuitive assumption, it is paramount in understanding the decisions that people make when they are experiencing pain, critically linked to the balance of deciding whether or not to engage with their environment [38]. We suggest that further investigation is warranted to explore the consequences of altered action in association with the experience of pain in order to better understand the circular causality of the perceptual inference process [39, 40].

Interpretation of this study should consider potential limitations. The participants were informed that there was a 50% chance that they would be required to walk the distance to the target, however none of the participants were actually asked to do so. We considered that this was critical if we were to overcome limitations of previous work, for example to standardise the prior state for each estimate, but it could open up the possibility that distance estimates were not made while anticipating action. This problem faces most studies investigating similar phenomena. In addition, we used an 11-point NRS for both pain and effort anticipation, this is a widely used and recognised scale, yet it may be considered a crude representation of cost for the individual; identifying more specific cost functions in individuals with chronic pain might benefit future studies in this field.

6. Conclusion

Our results do not support the Economy of Action hypothesis, whereby spatial perceptions would be scaled according to the anticipation of pain or effort. However, our results do not exclude the possibility, for which there is a large body of experimental evidence from other fields, that perception necessarily involves ubiquitous 'top-down' effects.

Author Contributions

Abby Tabor: Primary author, development of idea, manuscript preparation, data collection, analysis and interpretation

Owen O'Daly: development of idea, data analysis, manuscript editing

Robert W Gregory: participant recruitment, data analysis, manuscript editing

Clair Jacobs: participant recruitment, manuscript editing

Warren Travers: participant recruitment, manuscript editing

Michael A Thacker: development of idea, data analysis, manuscript editing

G Lorimer Moseley: Initial concept, development of idea, data analysis & interpretation, manuscript editing

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Variable	Patient	Control
Age	43.3 ±11.1	36.7 ±13.7
Duration of pain (Years)	12 ±9.7	0
Pain prior	6.5 ±1.5	0
Pain during	6.9 ±1.7	0
STAI (6-item)	12.4 ±3.7	8.94 ±2.7
Diagnosis Low Back Pain CRPS Multi site	 50% 9% 41%	N/A

Table 1. Participant demographic information (Mean ±SD

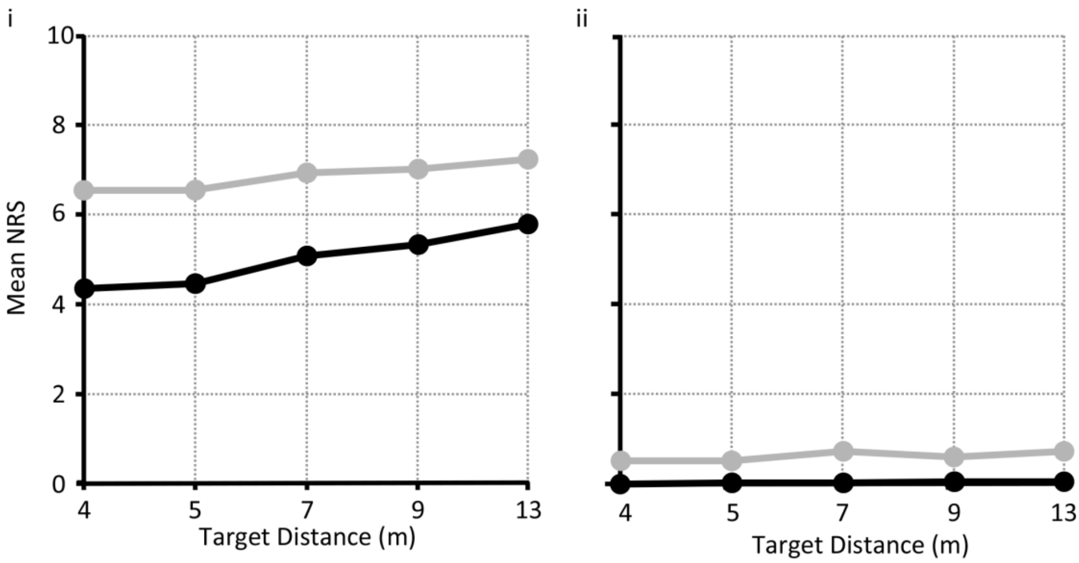

Fig. 1. Mean Numerical Rating Scale for each distance level. i. Chronic pain patients, ii. Pain-free controls. Grey lines represent Anticipated Effort, with black lines representing Anticipated Pain. Chronic pain patients anticipated that significantly more effort would be required to complete the task to walk to the target distance as compared to pain-free controls.

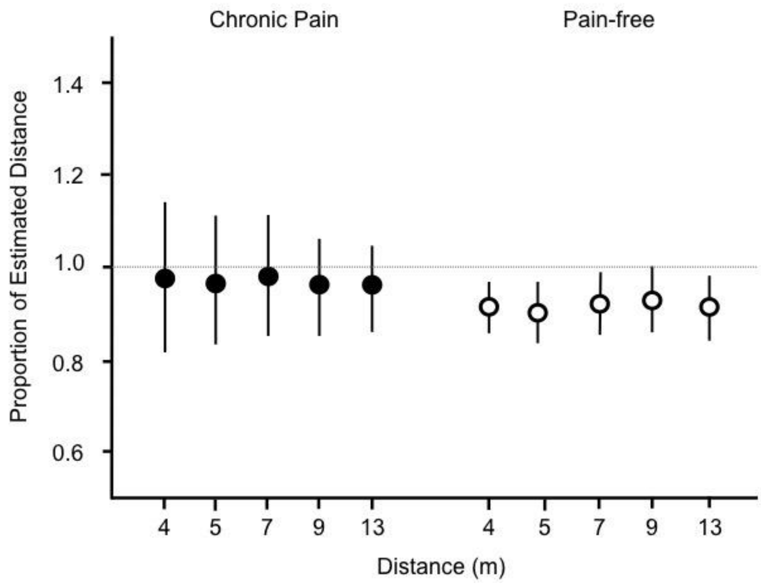

Fig. 2. Distance estimations as proportion of actual distance. Chronic pain patient (black circles) and pain free control (white circles) data are presented. Mean and 95% confidence intervals are shown for each distance.

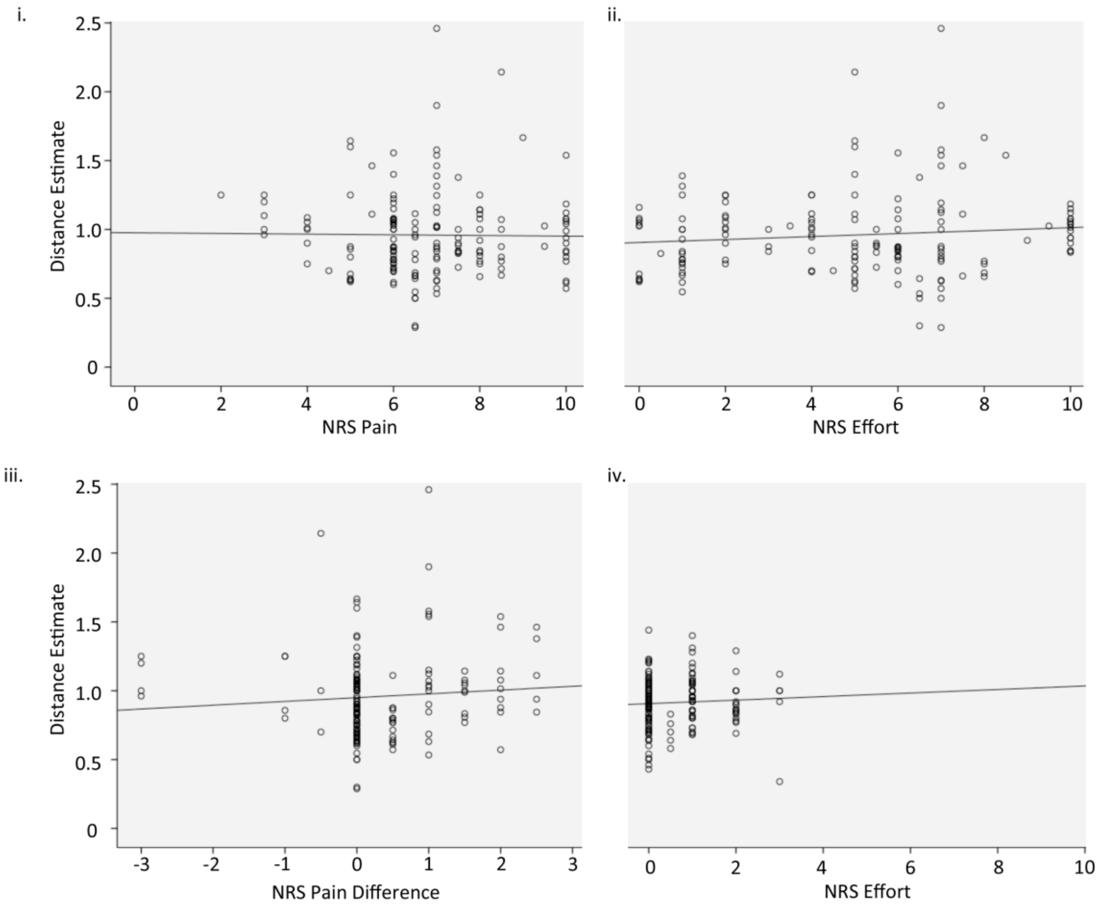

Fig. 3. Regression Analyses within the chronic pain group (i-iii) and control group (iv). i. Distance Estimate (as a proportion of Target Distance) * Numerical Rating Scale (NRS) Anticipated Pain, $F(1,154)=0.122$, $p=0.727$. ii. Distance Estimate (as a proportion of Target Distance) * Numerical Rating Scale (NRS) Anticipated Effort, $F(1,154)=1.171$, $p=0.281$. iii. Distance Estimate (as a proportion of Target Distance) * Difference NRS Anticipated Pain (Anticipated NRS Pain – Baseline NRS Pain), $F(1,154)=1.019$, $p=0.314$. iv. Distance Estimate (as a proportion of Target Distance) * NRS Effort in the control group, $F(1,154)=0.398$, $p=0.529$.