

Bond University
Research Repository



Bogus visual feedback alters onset of movement-evoked pain in people with neck pain

Harvie, Daniel S; Broecker, Markus; Smith, Ross T; Meulders, Ann; Madden, Victoria J; Moseley, G Lorimer

Published in:
Psychological Science

DOI:
[10.1177/0956797614563339](https://doi.org/10.1177/0956797614563339)

Licence:
Other

[Link to output in Bond University research repository.](#)

Recommended citation(APA):

Harvie, D. S., Broecker, M., Smith, R. T., Meulders, A., Madden, V. J., & Moseley, G. L. (2015). Bogus visual feedback alters onset of movement-evoked pain in people with neck pain. *Psychological Science*, *26*(4), 385-392. <https://doi.org/10.1177/0956797614563339>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

For more information, or if you believe that this document breaches copyright, please contact the Bond University research repository coordinator.

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

Bogus visual feedback alters movement-evoked pain onset in people with neck pain

Daniel S. Harvie, Markus Broecker, Ross T. Smith, Ann Meulders, Victoria J. Madden, G.

Lorimer Moseley

University of South Australia, Australia

Author Note

Daniel S. Harvie, Victoria J. Madden of the Samson Institute for Health Research, University of South Australia, and PainAdelaide, Adelaide, Australia; Markus Broecker, Ross Smith of The Wearable Computer Lab, University of South Australia, Australia; Ann Meulders of the Research Group on Health Psychology, Department of Psychology, University of Leuven, Belgium and Center for Excellence on Generalization Research in Health and Psychopathology, University of Leuven, Belgium; G. Lorimer Moseley of the Samson Institute for Health Research, University of South Australia, PainAdelaide, and Neuroscience Research Australia, Australia.

G. Lorimer Moseley is supported by an NHMRC Principal Research Fellowship ID 1061279. This study supported by NHMRC Grant ID 1047317. Ann Meulders is supported by a postdoctoral research grant of the Research Foundation-Flanders, Belgium (FWO-Vlaanderen) Grant ID 12E3714N and an EFIC-Grünenthal research grant E-G-G ID 169518451. The authors wish to thank Julie Peacock, Jonathon Schubert, William Kuang, Ellie Magarey (Marion Physiotherapy), Di Wilson, Peter Roberts, Eva Boesch and Toby Moen (Roberts Physiotherapy), Jason Collins and Glen Kocher (Northcare Physiotherapy) for assistance with recruitment and Anthony Ikiosoglous for assistance with blinded data extraction.

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

Correspondence concerning this article can be addressed to Lorimer Moseley, University of South Australia, GPO Box 2471, Adelaide, South Australia 5001.

E-mail: Lorimer.Moseley@gmail.com

Abstract

Pain is a protective perceptual response shaped by contextual, psychological and sensory inputs that suggest danger to the body. Sensory cues suggesting that a body part is moving towards a painful position, may credibly signal danger and thereby modulate pain. In this experiment, we used virtual reality to investigate whether manipulating visual-proprioceptive cues could alter movement-evoked pain, in 24 people with neck pain. We hypothesised that pain would occur at a lesser degree of head rotation when visual feedback overstated true rotation, and at a greater degree of rotation when visual feedback understated true rotation. Our hypothesis was clearly supported: when vision overstated the amount of rotation, pain occurred at 7% less rotation, and when vision understated rotation, pain occurred at 6% more rotation. We conclude that visual-proprioceptive information modulates movement-evoked pain threshold. This suggests that stimuli that become associated with pain, can themselves trigger pain.

Keywords: pain, perception, virtual reality, redirected walking, illusions, body representation, movement, multisensory processing.

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

Bogus visual feedback alters movement-evoked pain onset in people with neck pain

Introduction

Over the past three decades, the multidimensional nature of pain and nociception has been elucidated by research revealing that many factors, from sensory (Moseley & Arntz, 2007), cognitive (Wiech, Ploner, & Tracey, 2008; Brooks & Tracey 2005), and emotional (Wiech & Tracey, 2009; Brooks & Tracey 2005) domains, modulate pain. Critically, non-nociceptive somatosensory information can both modulate and evoke pain (Acerra & Moseley, 2005; Derbyshire, 2004; Arntz & Claassens, 2004), suggesting that pain is an ‘information-evoked’ response. The sensory cues capable of contributing to pain have not been well explored, although some authors suggest that any information that leads the brain to conclude that the body is in danger may evoke pain (Merksey & Bogduk, 1994; Moseley, 2003; Price, 1999; Arntz & Claassens, 2004).

This suggestion is not surprising, given what is known about other perceptual domains, where sensory elements combine into meaningful wholes. When perceiving a table, for example, we are not aware of individual colours, edges and shapes, but rather the unified whole (Goldstein, 2013; Hochstein & Ahissar, 2002; Weiten, 2007). There is ample psychological research investigating the principles underlying this sensory integration, particularly with respect to vision (Wagemans et al., 2012), but such principles have received scant attention in the study of pain.

Pain serves a protective function, so it is natural to think that non-nociceptive sensory information might help to determine whether pain is an appropriate perceptual response. For example, nociceptive input from a small laceration may evoke pain only after visual

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 information is added. Experimentally, non-nociceptive cues contingently paired with
4
5 nociceptive input (through classical conditioning) modulate the pain evoked by subsequent
6
7 nociceptive stimulation (Atlas, Bolger, Lindquist, & Wager, 2010; Keltner et al., 2006;
8
9 Koyama, McHaffie, Laurienti, & Coghill, 2005). It is assumed that, after such pairing, the
10
11 non-nociceptive cues become signals of body-related threat and thus join the suite of
12
13 information used by the brain to determine whether pain is an appropriate protective
14
15 perceptual response. This view is supported by experimental evidence showing that the pain
16
17 evoked by a nociceptive stimulus is affected by the meaning of both the nociceptive stimulus
18
19 and other non-nociceptive stimuli that are presented at the same time (Arntz & Claassens,
20
21 2004; Moseley & Arntz, 2007).
22
23
24

25
26 Very few studies have investigated the relationship between non-nociceptive
27
28 information and clinical pain. One study showed that people with complex regional pain
29
30 syndrome (CRPS) experienced pain when given visual input (via a mirror) suggesting touch,
31
32 despite the absence of actual touch (Acerra & Moseley, 2005). However, this procedure did
33
34 not evoke pain in a group with non-CRPS neuropathic hand pain (Krämer, Seddigh, Moseley,
35
36 & Birklein, 2008). One might therefore suggest that non-nociceptive cues are only important
37
38 in certain conditions. But if pain is ‘information-evoked’ — as we contend that it is — then a
39
40 threshold of relevant information, nociceptive and/or non-nociceptive, must be reached in
41
42 order to evoke pain. This idea is untested, but if relevant non-nociceptive input does affect
43
44 the amount of additional input required to evoke pain, it would effectively constitute a change
45
46 in pain threshold. One type of input that might have such influence is proprioceptive
47
48 information about specific movements and body positions. This is especially likely when a
49
50 vulnerable body part needs to be protected. In the instance of a neck injury, for example,
51
52 specific proprioceptive information might predict nociceptive stimulation and thus contribute
53
54 to defensive responses including pain.
55
56
57
58
59
60

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 In the present study, we tested the hypothesis that proprioceptive information might
4 contribute to pain by examining how altering visual-proprioceptive feedback during neck
5 rotation affects the range of motion to the onset of pain (movement-evoked pain threshold) in
6 longstanding neck pain sufferers. Using the 'information-based' view of pain, we
7 hypothesised that pain would occur earlier when visual-proprioceptive information overstated
8 real-world rotation, and later when visual-proprioceptive information understated real-world
9 rotation.
10
11
12
13
14
15
16
17
18
19
20
21
22

23 **Methods**

24 **Participants**

25
26
27
28
29 Twenty four individuals (6 males; mean age \pm SD = 45 \pm 15 years) volunteered to
30 participate in this study. Sample size was determined a priori to enable detection of a small-
31 medium effect size ($f = 0.2$) with 80% power, conservatively assuming a 60% correlation
32 among repeated measures. The average duration of complaint was 11 years ($SD = 11$; range:
33 2 months to 45 years) and the participant's physiotherapists described their pain conditions as
34 resulting primarily from posture/tension/repeated strain ($n=9$), whiplash ($n=7$), degeneration
35 ($n=5$), trauma ($n=2$) and scoliosis ($n=1$). Participants were mildly to moderately disabled
36 (Neck Pain Disability Index score \pm SD = 29% \pm 13%). Participants were recruited through
37 local physiotherapy clinics and were reimbursed AU\$20 for their participation. Participants
38 were excluded if they had pain-free neck rotation, were unable to tolerate repeated rotation to
39 the first onset of pain, had severely impaired vision, were under the age of 18 or if their
40 physiotherapist had identified significant neurological impairments such as sensory or motor
41 deficits and easily provoked, constant or progressive upper limb dysaesthesia. The protocol
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

was approved by the Human Research Ethics Committee of the University of South Australia
(Protocol number: 31537).

Stimulus material and apparatus

A VR technique known as ‘re-directed walking’ modulates visual-proprioceptive feedback by tracking real-world movement and then feeding this back into the virtual environment in under- or over-stated form, creating the illusion of more or less movement than is actually happening. Within certain limits, participants remain unaware of the manipulation (Steinicke, Bruder, Jerald, Frenz, & Lappe, 2008). An Oculus Rift VR Head Mounted Display (HMD) designed for immersive VR environments was used. The HMD shown in Figure 1 displayed a virtual world and recorded head movement using internal gyroscopes. Customised software was used to apply the selected rotation gains and map each of six scenes to the virtual template. The six scenes included four outdoor scenes (a park, a mountain, a countryside and church grounds) and two indoor scenes (a dining room and a living room).



Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 **Fig 1.** Set-up of the VR experiment showing a supportive chair with trunk fixation,
4
5 headphones, head mounted display and the 360° (cylindrical) virtual template which
6
7 accommodated the six virtual scenes.
8
9

10 **Experimental design**

11
12
13
14 The study had a within-subject, randomised, double-blinded, repeated-measures
15
16 design. The range of neck rotation to the first onset of pain was quantified in three conditions
17
18 where virtual rotation was (a) 20% less than (rotation gain = 0.8), (b) equal to (rotation gain =
19
20 1) or (c) 20% greater than (rotation gain = 1.2) actual physical rotation. The order of the
21
22 three conditions was counterbalanced among participants, creating six possible orders. Four
23
24 participants were assigned to each of these counterbalancing orders according to a pre-
25
26 randomised order. Participants were blinded to the experimental manipulation and study
27
28 purpose, and the files relating to the three VR conditions were coded, thereby blinding the
29
30 experimenter to the order of conditions. The measurement of neck rotation was automated
31
32 and data were only extracted after all the data had been collected (A.I.).
33
34
35

36 **Measurement**

37
38
39 Axial neck rotation to the onset of pain was measured in degrees. Because
40
41 participants stopped at the first onset of pain in each trial, the range of motion to onset of pain
42
43 was defined as the peak rotation for each trial. This measure was extracted from each
44
45 automated trial output by a blinded assessor (A.I.).
46
47
48

49 **Protocol**

50
51
52 In order to prevent changes in postural alignment and to isolate neck movement,
53
54 subjects were seated in a supportive chair with the torso fixed in place by a seatbelt at the
55
56 level of the shoulders (see Figure 1). A laser pointer was fixed to the HMD and used to mark
57
58
59
60

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 the starting position on the wall as a physical reference point for ‘zeroing’ of the gyroscopes
4
5 between measures and conditions. Participants wore white noise-emitting headphones to
6
7 counter any incidental noise, which might inform head orientation and disrupt the illusion.
8
9

10
11 For each of the three conditions, participants were asked to rotate slowly to the left,
12
13 stopping at the very first onset of pain, and then to return to the centre. Once the head had
14
15 returned to centre, the next trial was loaded and the task repeated to the right. Each condition
16
17 consisted of six left-rotation and six right-rotation measures. After each condition,
18
19 participants were asked to rate the average pain intensity experienced, for each rotation
20
21 direction to allow for subsequent assessment of any overall differences in pain intensity
22
23 between conditions. A 0-10 numerical rating scale (NRS) was used with anchors 0 = no pain
24
25 and 10 = the worst imaginable pain. To minimise the possibility that subjects would become
26
27 aware of the different rotation settings and thus directly compare them, each condition was
28
29 separated by a three-minute interval. In addition, six changing VR scenes acted as a decoy
30
31 from the actual study purpose and reduced the risk of participants’ anchoring their rotation to
32
33 a previous visual cue within a VR scene. In order to assess blinding, participants were asked
34
35 on completion of the experiment if they noticed anything different between the three
36
37 conditions.
38
39
40
41

42 **Manipulation check 1: Setting boundaries for altered visual-proprioceptive feedback**

43
44
45 VR operates by tracking real-world changes in orientation and applying this to the
46
47 virtual world being experienced via the HMD. The ‘rotation gain’ (the factor by which real
48
49 rotation is translated to virtual rotation) can be manipulated such that virtual and physical
50
51 rotation differ. In order to blind participants to this manipulation, the upper and lower limits
52
53 of the rotation gain were based on the results of a pilot study. During this pilot study, an
54
55 independent cohort of nine healthy participants (7 males; $M_{\text{age}} = 32$ years, $SD_{\text{age}} = 12$) were
56
57
58
59
60

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

presented with a range of rotation gain settings and asked to rotate their heads. They were to indicate when a difference between real and virtual rotation occurred by judging the observed rotation as slower than, equal to, or faster than their true physical rotation. We aimed to determine the rotation gain at which participants were more likely to judge the virtual and real rotation to be equal than they were to judge them to be different. As shown in Figure 2, the rotation gains that corresponded to these points were 0.72 and 1.18. As a result, our experimental gain settings were chosen to fall between 0.8 and 1.2, and additional controls were implemented to ensure that participants in the main study remained blinded.

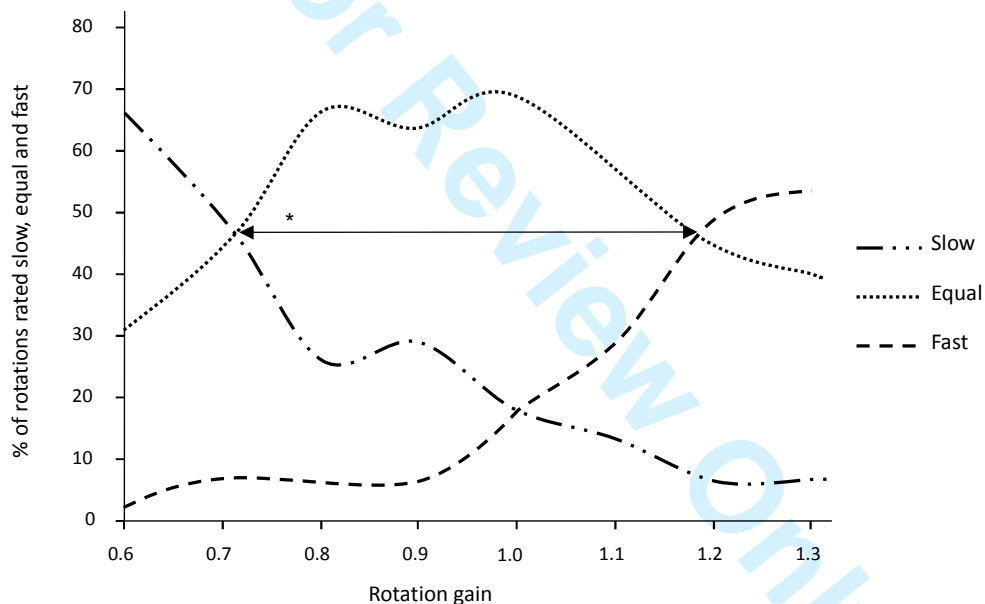


Fig 2. The percentage of rotation trials rated as slow, equal or fast for each rotation gain setting. * indicates the range of rotation gain settings where virtual and real-world movement speeds were perceived as being equal more often than faster or slower.

Manipulation check 2: Reliability and validity of measurement

The reliability of the gyroscopic measurement of rotation was tested by attaching the HMD to a mechanical (goniometric) arm and testing its ability to repeatedly and accurately

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 measure three set angles (20°, 40°, and 60°). Initial observation of repeated measures
4
5 revealed that while the measurement was highly precise over a small number of trials, it
6
7 gradually drifted with more trials. Therefore, a protocol was developed which required the
8
9 virtual compass to be 'zeroed' every 5 trials. To further prevent accumulation of error, the
10
11 programme was refreshed between conditions. This protocol was found to have a correlation
12
13 with actual rotation of $r = .994$, and a high degree of precision for repeated measures at
14
15 20° ($M = 19.8^\circ$, $SD = 0.8^\circ$), 40° ($M = 39.6^\circ$, $SD = 0.3^\circ$) and 60° ($M = 59.1^\circ$, $SD = 2.5^\circ$).
16
17
18

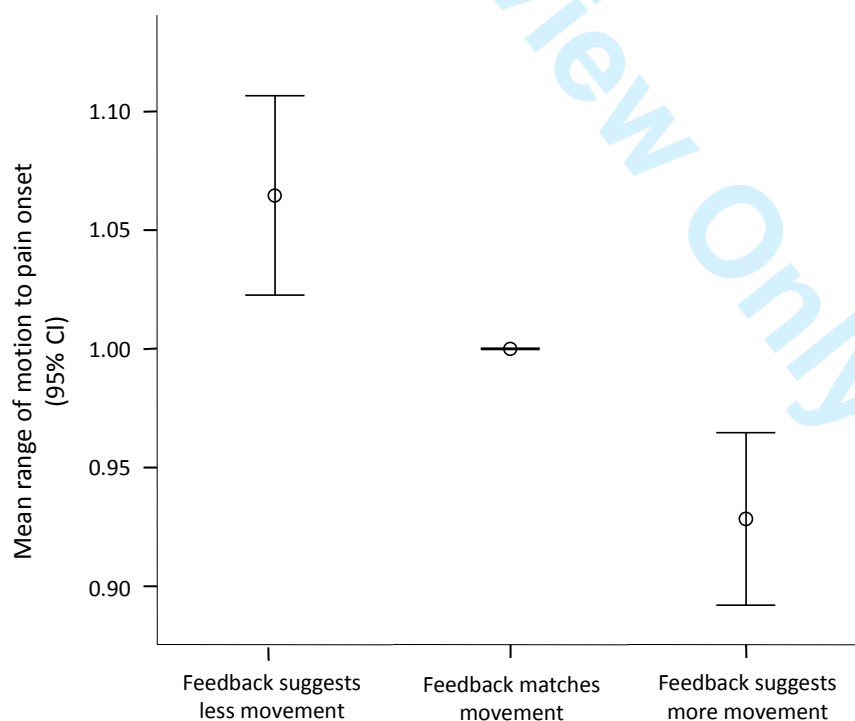
19 **Data extraction and statistical analysis overview**

20
21
22 In order to test the main hypothesis that visual information that overstates or
23
24 understates true rotation can affect movement-evoked pain, we compared the range of motion
25
26 to first onset of pain between the three conditions, using repeated-measures ANOVA with
27
28 Bonferroni-corrected pairwise comparisons. In order to account for between-subject
29
30 differences in range of motion, data for each participant were transformed to 'a proportion of
31
32 the average range of motion demonstrated in the neutral condition'. Alpha was set at $p <$
33
34 0.05 and the effect sizes partial eta squared (η_p^2) and Cohen's d were interpreted with respect
35
36 to Cohen's guidelines (0.01 = small, 0.059 = medium and 0.138 = large; and 0.2 = small, 0.5
37
38 = medium, 0.8 = large respectively) (Cohen, 1988). As a manipulation check, each
39
40 participant's average movement-evoked pain for each condition was normalised to a
41
42 proportion of their average across conditions. Normalised pain ratings were then compared
43
44 between conditions using repeated-measures ANOVA.
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Results

Primary outcome: Range of motion to pain onset

The repeated-measures ANOVA revealed a large overall effect of visual-proprioceptive feedback (Condition) on pain-free range, $F(2, 135) = 18.35, p < .001, \eta_p^2 = 0.214$. All pairwise comparisons were significant ($p < .014$). When vision understated true rotation, there was a *medium effect* toward increased range of motion to the first onset of pain, $p = .014, d = 0.65$; and when vision overstated true rotation, there was a *large effect*, this time, toward decreased range of motion to the first onset of pain, $p = .005, d = 0.83$. That is, the visual feedback was able to delay the onset of pain by 6% (CI 2-11%) or advance it by 7% (CI 4-11%), showing an overall manipulation of 13%.



Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

Fig. 4. Mean (circle) and 95% confidence interval (error bars) for the range of motion to first onset of pain presented as a proportion of the mean range of rotation for the neutral condition.

Pain intensity across conditions

The repeated-measures ANOVA did not reveal any difference in pain intensity between conditions ($p = 0.6$). That is, any difference in rotation could not be explained by participants' actually moving beyond or stopping short of their pain threshold, which strengthens our confidence in the main finding. In fact, inspection of Figure 3 hints at more pain in the condition where visual feedback suggested more movement, further reinforcing the finding that the visual suggestion of more movement increases sensitivity.

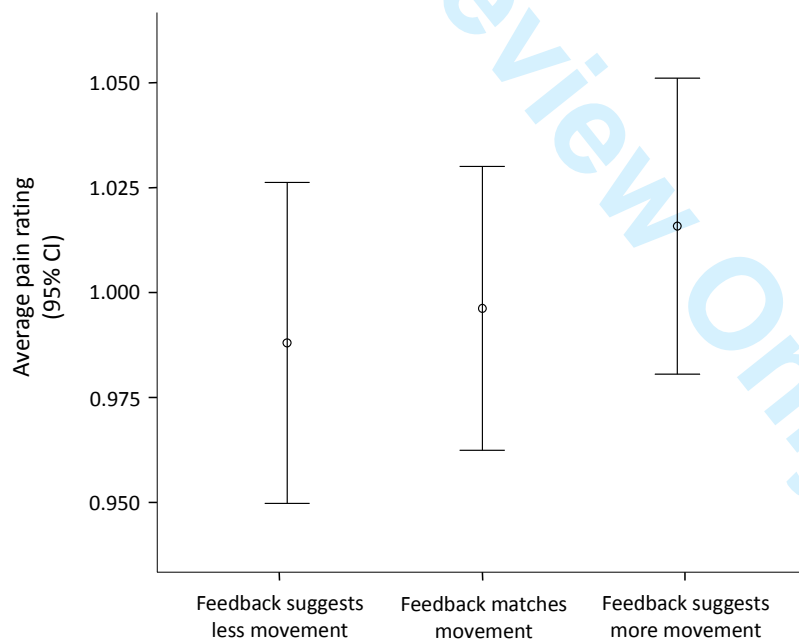


Fig. 3. Mean (circles) and 95% confidence interval (error bars) for the normalised pain ratings reported for neck rotation in each condition.

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

Discussion

We examined how altering visual-proprioceptive feedback during neck rotation affects the range of motion to the onset of pain (the movement-evoked pain threshold) in longstanding neck pain sufferers. Using the ‘information-based’ view of pain, we hypothesised that pain would occur at a lesser degree of head rotation when visual-proprioceptive information overstated true rotation, and at a greater degree when visual-proprioceptive information understated true rotation. The hypothesis was clearly supported – visual feedback that overstated neck rotation resulted in pain onset occurring at a lesser degree of movement (reduced pain threshold), whereas visual feedback that understated neck rotation resulted in pain onset occurring at a greater degree of movement (increased pain threshold). The finding that visual-proprioceptive cues may contribute to a pain-evoking sensory suite is particularly relevant because chronic pain is most commonly provoked by particular movements and body positions.

Our results appear consistent with the view of pain as the perceptual result of the brain’s inference that body tissue is in danger (Merksey & Bogduk, 1994; Moseley, 2003; Price, 1999; Arntz & Claassens, 2004) and corroborate related evidence of the relationship between experienced pain intensity and cues that imply threat to tissue (Arntz & Claassens, 2004; Atlas & Wagner 2012; Moseley & Arntz, 2007; Wiech et al., 2010). For example, a noxious cold stimulus evokes more pain if it is accompanied by a red light than if it is accompanied by a blue one (Moseley & Arntz, 2007); a noxious laser stimulus evokes more pain, and different cortical activation, if it is delivered to an area of skin thought by the participant to be ‘thinner than normal’ than if it is delivered to skin thought to be normal (Wiech et al., 2010). Such examples offer compelling evidence that pain can be modulated if there is credible evidence of tissue danger, even if that evidence is not from the nociceptive

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 domain. The current results offer a new direction however, because they show a shift in pain
4
5 threshold, rather than an upregulation of pain. This is important because most examples of
6
7 amplification of pain can be explained by enhanced sensitivity within the nociceptive system
8
9 – most notably termed ‘central sensitisation’. We contend that our results, of a reduced pain
10
11 threshold to movement, are very unlikely due to central sensitisation because that would be
12
13 more likely to manifest in the opposite result – greater pain increase in response to greater
14
15 magnitude of movement. We contend that the most obvious explanation for the current
16
17 results is associative learning. That is, neck rotation involves a suite of motor, visual and
18
19 proprioceptive processes that, for the person with neck pain, becomes associated with
20
21 nociceptive input, such that the non-nociceptive aspects of the sensorial suite are sufficient to
22
23 trigger pain with or without the nociceptive component.
24
25
26

27
28 That the effect clearly relies on visual input triggering some sort of ‘threat threshold’,
29
30 does not exclude the possibility that non-cortical mechanisms are involved. Most obvious
31
32 here is the descending modulatory system, whereby primarily brainstem nuclei exert both
33
34 inhibitory and facilitatory influences over dorsal horn neurones (see Woolf & Slater, 2006 for
35
36 review). According to modern models of pain, however, the evaluative processes that
37
38 subserve descending modulation are grounded in those that subserve the production of pain
39
40 itself. That is, pain can be considered to reflect the perceived need to protect body tissue;
41
42 descending modulation can be considered a ‘correction’ of spinal nociceptor activity (i.e. the
43
44 ‘danger message’) so as to bring it into line with the brain’s evaluation of true danger (see
45
46 Moseley, 2007; Butler, 2013; Fields, 2006). This understanding is analogous to that applied
47
48 to motor control, whereby motor commands are corrected according to somatosensory and
49
50 visual feedback (Sperry, 1950; Von Holst, 1950). Those models are also relevant here
51
52 because it is also possible that the bogus visual feedback modulates proprioceptive sensitivity
53
54 (Gandevia, Refshauge & Collins, 2002), which in turn may modulate nociceptive input.
55
56
57
58
59
60

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 Notably, the pain advancing effect of overstating rotation was greater than the pain
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Notably, the pain advancing effect of overstating rotation was greater than the pain delaying effect of understating rotation, indicating that visual feedback had a greater ability to advance than delay pain. This finding fits with the greater potential cost of a perceptual error that delays the onset of pain, which is consistent with inferential perceptual models (i.e. Bayesian) that include a cost function (Feldman, 2013; Tabor, Catley, Gandevia, Thacker, & Moseley, 2013).

Although the current work was experimental in nature, it raises intriguing potential clinical implications. First, our results clearly suggest a rethink of how we interpret simple clinical tests such as movement-evoked pain. Such tests are widely held to reflect sensitivity of tissues and nociceptive pathways – repeatable and stable movement-evoked pain thresholds are considered to be consistent with a primary nociceptive driver of pain – the presence of tissue pathology (Jones & Rivett, 2004). However, our results suggest that this is a naïve perspective. As such, it is not unreasonable to suggest that a VR set-up such as that used here might play a role in the assessment of people in pain, to identify and quantify the role of non-nociceptive somatosensory cues in pain and impairment. Second, if cues signalling danger amplify or indeed trigger pain, then these cues present a novel target for therapy. One way to extinguish the effect of such cues on pain might be to experientially dissociate them from pain. For example, the re-directed walking techniques used in this study can provide the illusory experience of large movements, but limit real-world movement and pain. This idea might also be relevant to the use of visual illusory movements administered by a mirror – common interventions for chronic limb pain conditions including phantom limb pain and complex regional pain syndrome (Moseley, 2004; Moseley, 2006; Ezendam, Bongers & Jannik, 2009; Bowering et al., 2012; Daly & Bialocerkowski, 2009) use mirror-therapy, but the idea of distorting the feedback as a method of disentangling non-nociceptive movement-related cues appears to have not been considered.

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 The relationship observed here, between potentially threatening information and
4 movement-evoked pain, might also provide insight as to why cognitive and behavioural
5 interventions, such as education and exposure, which target perceived threat/pain-related fear,
6 also positively alter the relationship between movement and pain (Moseley, 2004; Vlaeyen,
7 de Jong, Geilen, Heuts, & van Breukelen, 2002). Whilst education, for example, may aim to
8 convince a patient that their pain is not a direct correlate of tissue stress, demonstrating this
9 with real-time evidence that their pain depends on visually encoded movement not actual
10 movement, may have therapeutic power.
11
12
13
14
15
16
17
18
19

20
21 Further research using the current framework might exploit more immersive and
22 multisensory VR, which may enable the delivery of more convincing and multimodal illusory
23 evidence of danger to the body. Further studies could also investigate how visual-
24 proprioceptive and other cues might acquire the ability to modulate/mediate pain (i.e. through
25 associative learning) as well as investigate why the effect might persist or over-generalise,
26 and how it might be extinguished. Disentangling pain from nociception is a challenge that
27 has been identified in experimental and cognitive psychology research (Moseley, 2012), but
28 the methodology used here lays a platform from which this challenge might be taken on.
29
30
31
32
33
34
35
36
37
38
39
40
41

42 Conclusion

43
44
45 In people with neck pain, when visual-proprioceptive feedback overstates true neck
46 rotation, neck pain occurs at a lesser degree of head rotation. When visual-proprioceptive
47 feedback understates true neck rotation, neck pain occurs later. We conclude, then, that
48 visual-proprioceptive information modulates pain threshold during head rotation in people
49 with neck pain. This has broad implications for our view of pain as an ‘information-evoked’
50 response and supports further investigation of non-nociceptive contributions to long-standing
51
52
53
54
55
56
57
58
59
60

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

1
2
3 pain. Furthermore, the methodology outlined here presents a new method for theoretical and
4
5 experimental interrogation of pain, and raises the possibility of novel assessment and
6
7 therapeutic applications.
8
9

10 11 12 13 14 **Author contributions**

15
16
17 D.S.H and G.L.M. developed the study concept, contributed to design, data analysis,
18
19 interpretation and write-up. D.S.H. collected the data. V.J.M. contributed to study design and
20
21 write-up. M.B. and R.T.S contributed to study design and provided technical expertise for the
22
23 VR set-up. A.M. contributed to interpretation and write-up. All authors approved the final
24
25 version of the manuscript for submission.
26
27
28
29
30
31
32
33

34 **References**

- 35
36 Acerra, N. E., & Moseley, G. L. (2005). Dysynchiria: watching the mirror image of the unaffected
37 limb elicits pain on the affected side. *Neurology*, *65*(5), 751-753.
38 Arntz, A., & Claassens, L. (2004). The meaning of pain influences its experienced intensity. *Pain*,
39 *109*(1-2), 20-25.
40 Atlas, L. Y., Bolger, N., Lindquist, M. A., & Wager, T. D. (2010). Brain mediators of predictive cue
41 effects on perceived pain. *The Journal of Neuroscience*, *30*(39), 12964-12977.
42 Atlas, L. Y., & Wager, T. D. (2012). How expectations shape pain. *Neuroscience Letters*, *520*(2),
43 140-148.
44 Bowering, K. J., O'Connell, N. E, Tabor, A., Catley, M. J., Leake, H. B., Moseley, G. L., & Stanton,
45 T. R. (2013). The effects of graded motor imagery and its components on chronic pain: a
46 systematic review and meta-analysis. *The Journal of Pain*, *14*(1), 3-13.
47 Butler, D. S., & Moseley, G. L.. (2013). *Explain Pain:(Revised and Updated: Noigroup Publications*.
48 Carruthers, G. (2008). Types of body representation and the sense of embodiment. *Consciousness and*
49 *cognition*, *17*(4), 1302-1316.
50 Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. London, UK: Routledge.
51 Daly, A. E., & Bialocerkowski, A. E. (2009). Does evidence support physiotherapy management of
52 adult Complex Regional Pain Syndrome Type One? A systematic review. *European Journal*
53 *of Pain*, *13*(4), 339-353.
54 Ezendam, D., Bongers, R. M., & Jannink, M. J. A. (2009). Systematic review of the effectiveness of
55 mirror therapy in upper extremity function. *Disability & Rehabilitation*, *31*(26), 2135-2149.
56 Feldman, J. (2013). Bayesian models of perceptual organization. *Handbook of perceptual*
57 *organization*.
58
59
60

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

- 1
2
3 Fields, H. L., Basbaum, A. I., & Heinricher, M. M. (2006). Wall and Melzack's Textbook of Pain. *SB*
4 *McMahon and M Koltzenburg. Wall and Melzack's Textbook of Pain. UK: Elsevier Churchill*
5 *Livingstone*, 125-130.
- 6 Gandevia, S. C., Refshauge, K. M., & Collins, D. F. (2002). Proprioception: peripheral inputs and
7 perceptual interactions *Sensorimotor Control of Movement and Posture* (pp. 61-68): Springer.
- 8 Goldstein, E B. (2014). *Sensation and perception* (6th ed.). Belmont, CA: Wadsworth-Cengage
9 Learning.
- 10 Hochstein, S., & Ahissar, M. (2002). View from the top: Hierarchies and reverse hierarchies in the
11 visual system. *Neuron*, 36(5), 791-804.
- 12 Jones, M. A., & Rivett, D. A. (2004). Chapter 1 - Introduction to clinical reasoning. In M. A. J. A.
13 Rivett (Ed.), *Clinical Reasoning for Manual Therapists* (pp. 3-24). Oxford: Butterworth-
14 Heinemann.
- 15 Keltner, J. R., Furst, A., Fan, C. R., Rick, I. B., & Fields, H. L. (2006). Isolating the modulatory effect
16 of expectation on pain transmission: a functional magnetic resonance imaging study. *The*
17 *Journal of neuroscience*, 26(16), 4437-4443.
- 18 Koyama, T., McHaffie, J. G., Laurienti, P. J., & Coghill, R. C. (2005). The subjective experience of
19 pain: where expectations become reality. *Proceedings of the National Academy of Sciences of*
20 *the United States of America*, 102(36), 12950-12955.
- 21 Krämer, H. H., Seddigh, S., Moseley, G. L., & Birklein, F. (2008). Dysynchiria is not a common
22 feature of neuropathic pain. *European Journal of Pain*, 12(1), 128-131.
- 23 Merksey, H., & Bogduk, N. (1994). Classification of chronic pain. *Seattle: International Association*
24 *for the Study of Pain Press*, 194, 210.
- 25 Moseley, G. L. (2007). Reconceptualising pain according to its underlying biology. *Phys. Ther. Rev*,
26 12, 169-178.
- 27 Moseley, G. L. (2006). Graded motor imagery for pathologic pain A randomized controlled trial.
28 *Neurology*, 67(12), 2129-2134.
- 29 Moseley, G. L., Gallace, A., & Spence, C. (2012). Bodily illusions in health and disease:
30 physiological and clinical perspectives and the concept of a cortical 'body matrix'.
31 *Neuroscience & Biobehavioral Reviews*, 36(1), 34-46.
- 32 Moseley, G. L. (2004). Graded motor imagery is effective for long-standing complex regional pain
33 syndrome: a randomised controlled trial. *Pain*, 108(1), 192-198.
- 34 Moseley, G. L. (2007). Reconceptualising pain according to its underlying biology. *Phys. Ther. Rev*,
35 12, 169-178.
- 36 Moseley, G. L. (2004). Evidence for a direct relationship between cognitive and physical change
37 during an education intervention in people with chronic low back pain. *European Journal of*
38 *Pain*, 8(1), 39-45.
- 39 Moseley, G. L., & Arntz, A. (2007). The context of a noxious stimulus affects the pain it evokes.
40 *Pain*, 133(1), 64-71.
- 41 Moseley, G. L., Gallace, A., & Spence, C. (2012). Bodily illusions in health and disease:
42 Physiological and clinical perspectives and the concept of a cortical 'body matrix'.
43 *Neuroscience & Biobehavioral Reviews*, 36(1), 34-46.
- 44 Moseley, G. L. (2003). A pain neuromatrix approach to patients with chronic pain. *Manual therapy*,
45 8(3), 130-140.
- 46 Mountcastle, V. B. (2005). *The sensory hand: neural mechanisms of somatic sensation*. Cambridge,
47 MA: Harvard University Press.
- 48 Price, Donald D. (1999). *Psychological mechanisms of pain and analgesia*. Seattle, WA: IASP press.
- 49 Ro, T., Wallace, R., Hagedorn, J., Farnè, A., & Pienkos, E. (2004). Visual enhancing of tactile
50 perception in the posterior parietal cortex. *Journal of Cognitive Neuroscience*, 16(1), 24-30.
- 51 Steinicke, F., Bruder, G., Jerald, J., Frenz, H., & Lappe, M. (2008). *Analyses of human sensitivity to*
52 *redirected walking*. Paper presented at the Proceedings of the 2008 ACM symposium on
53 Virtual reality software and technology.
- 54 Sperry, R. W. (1950). Neural basis of the spontaneous optokinetic response produced by visual
55 inversion. *Journal of comparative and physiological psychology*, 43(6), 482.
- 56
57
58
59
60

Running head: VISUAL FEEDBACK ALTERS MOVEMENT-EVOKED PAIN

- 1
2
3 Tabor, A., Catley, M. J., Gandevia, S., Thacker, M. A., & Moseley, G. L. (2013). Perceptual bias in
4 pain: a switch looks closer when it will relieve pain than when it won't. *Pain*.
5 Tracey, Irene. (2010). Getting the pain you expect: mechanisms of placebo, nocebo and reappraisal
6 effects in humans. *Nat Med*, *16*(11), 1277-1283.
7 Vlaeyen, J. W.S., de Jong, J., Geilen, M., Heuts, P. H. T. G., & van Breukelen, G. (2002). The
8 treatment of fear of movement/(re) injury in chronic low back pain: further evidence on the
9 effectiveness of exposure in vivo. *The Clinical journal of pain*, *18*(4), 251-261.
10 Von Holst, E. (1950). Die Arbeitsweise des Statolithen-apparates bei Fischen. *Zeitschrift für*
11 *vergleichende Physiologie*, *32*(1-2), 60-120.
12 Vos, T., Flaxman, A. D., Naghavi, M., Lozano, R., Michaud, C., Ezzati, M., . . . Aboyans, V. (2013).
13 Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010:
14 a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, *380*(9859),
15 2163-2196.
16 Wagemans, J., Elder, J. H., Kubovy, M., Palmer, S. E., Peterson, M. A., Singh, M., & von der Heydt,
17 R. (2012). A century of Gestalt psychology in visual perception: I. Perceptual grouping and
18 figure–ground organization. *Psychological bulletin*, *138*(6), 1172.
19 Weiten, W. (2007). *Psychology: Themes and Variations: Themes And Variations*: Cengage Learning.
20 Wiech, K., Lin, Chia-shu, B., Kay H., Bingel, U., Ploner, M., & Tracey, I. (2010). Anterior insula
21 integrates information about salience into perceptual decisions about pain. *The Journal of*
22 *Neuroscience*, *30*(48), 16324-16331.
23 Wiech, K., Ploner, M., & Tracey, I. (2008). Neurocognitive aspects of pain perception. *Trends in*
24 *cognitive sciences*, *12*(8), 306-313.
25 Wiech, K., & Tracey, I. (2009). The influence of negative emotions on pain: behavioral effects and
26 neural mechanisms. *Neuroimage*, *47*(3), 987-994.
27 Woolf, C. J., & Salter, M. W. (2006). Plasticity and pain: role of the dorsal horn. *Wall and Melzack's*
28 *textbook of pain*, *5*, 91-105.
29 Yolton, J. W. (1996). *Perception & reality: A history from Descartes to Kant*: Cornell University
30 Press Ithaca.
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60