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Review article

Non-informative vision enhances tactile acuity: A systematic review and meta-analysis

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ABSTRACT

Background: Individual experimental data suggest that visual input during tactile stimulation enhances tactile appreciation – whether this finding is replicated across studies and across body sites is unknown.
Objective: To determine the available evidence as to whether non-informative vision of the body has an effect on tactile acuity.
Methods: Studies that assessed tactile acuity with vision of the body, compared to vision of a neutral object or vision occluded, were systematically identified and reviewed. Seven relevant electronic databases were searched from their inception to April 2014. Risk of bias was assessed using adapted criteria from the Cochrane Handbook. Effect sizes were calculated using mean differences in a random effects model.
Results: Ten studies were included. All were randomized, within subject, controlled trials published in English (total $n=232$ participants), with low to moderate risk of bias. Despite the diversity of protocols and outcome measures used, eight of the studies reported improvements in tactile acuity when vision of the relevant body part (predominantly the hand) was available. Meta-analysis revealed statistically significant findings from grating orientation tests ($p=0.002$, *SMD* 3.31, 95% CI 1.24–5.39), demonstrating a positive effect of vision of the body. No significant effect was found for other sensory tests or for other body parts, such as the back, and statistical heterogeneity was high.
Conclusions: This review provides confirmatory evidence for a visual enhancement effect for tactile acuity for body parts where vision has a plausible functional linkage – further studies are required to elaborate on the mechanisms for multi-modal processing of sensory stimuli.

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1. Introduction

Perception is now considered the result of multimodal processing, rather than a direct read-out of tactile input (Halligan et al., 1997). Indeed, there has been sufficient investigation of this possibility in fundamental studies to lead to the idea of a "visual enhancement of touch" (VET) effect (Kennett et al., 2001; Taylor-Clarke et al., 2004; Cardini et al., 2011). The mechanisms behind VET in humans are still largely unknown, but animal studies have uncovered neurons in parietal and frontal cortex that have tactile receptive fields on the hand, and corresponding visual receptive fields in the space immediately adjacent to those tactile receptive fields (Rizzolatti et al., 1997). There are some behavioral and neuroimaging data that imply that a functionally analogous system may exist in humans (Taylor-Clarke et al., 2004; Sereno and Huang, 2006). Serino and Haggard (2010, p. 233) reviewed the phenomenon of VET concluding: "The neural correlates of this effect may involve activation of multimodal brain areas representing the body, which results in a modulation of neural activity in primary somatosensory cortex."

This systematic review aimed to determine the current state of evidence as to whether non-informative vision of the body has an effect on tactile acuity in humans. Vision was defined as non-informative in that there was vision of the body part being stimulated or tested, but no vision of the tactile stimulus being given.

2. Methods

2.1. Systematic search strategy

The electronic databases CINAHL, EMBASE, MEDLINE, PEDro, SCOPUS, TRIP and Web of Science were searched from their inception to November 2014. The search was conducted in each database using the following terms: "touch* OR tactile AND vision OR look* OR watch*" (Boolean operator * adapted as necessary for each database). Each search was restricted to the English language with no other publication restrictions imposed and participant type was limited to a healthy population of adults ($\geq$ 18 years). The intervention of interest was the use of vision during tactile acuity testing as compared to vision of a neutral object or occluded vision, with tactile acuity as the primary outcome.

Titles of the initial search were screened by one reviewer. Eligibility assessment of the abstracts of remaining studies was then undertaken independently by two reviewers, with studies progressed through this selection process using a yes/no/maybe format. Full-text papers were then assessed by both reviewers. Any disagreements between reviewers were to be resolved through discussion. Reference lists of included papers were also searched.

2.2. Critical appraisal

Methodological quality of the included studies was assessed for risk of bias based on an adaptation of the criteria recommended in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins et al., 2011). Risk of bias (also known as critical appraisal) offers a structured and repeatable method to evaluate the level of threat to the internal validity of included studies—a low risk of bias is interpreted as evidence that the results of the study are highly credible and unlikely to be confounded by poor study methods. Five criteria were established: randomising/counterbalancing, blinding, selective reporting, ethical considerations and sampling. Both reviewers independently assessed individual studies for risk of bias and then compared results, using three levels: low (yes, met criterion), potential (unclear if met criterion) or high risk of bias (no, did not meet criterion). Discrepancies were discussed and resolved by consensus.

2.3. Data extraction and analysis

A data extraction sheet was developed by both reviewers for details of study design, participant characteristics, intervention and comparison, and outcome measures. Where studies were sufficiently homogenous, meta-analyses would be performed; if this was not possible a descriptive synthesis of study results would then be undertaken. The primary measure of effect for both meta-analyses was the difference in means and standard deviations for the outcome of tactile acuity, using random effects to accommodate study heterogeneity (RevMan v5.2).

3. Results

3.1. Study selection

Ten studies were included in this review. The initial database search resulted in 432 citations. One reviewer then excluded 401 citations based on title and abstract. Thirty-one full text studies were assessed by both reviewers, resulting in exclusion of a further 25 studies. At this stage, six studies that assessed the effect of non-informative vision of the body vs. vision of a neutral object or vision occluded on tactile acuity were included. Subsequent pearling of the reference lists of these included papers yielded four additional studies, which were then assessed by both reviewers and included. Details of inclusion/exclusion criteria at each stage of the systematic review are detailed in Table 1. A flow diagram of

Table 1
Inclusion/exclusion criteria for each stage.

Assessment stage	Inclusion criteria	Exclusion criteria
Titles	Adults ($\geq$ 18 years)	Children (< 18 years)
	Healthy population	Patient population
	English language	Non-English language papers
Abstracts	Undertook tactile sensory testing with a visual aspect	No visual aspect to sensory testing
	Outcome measure of tactile acuity	Tactile acuity not assessed (e.g. assessed a different sensory modality)
Full-text	Conditions of vision of the body, vs. vision occluded or vision of object	Illusion or reflected images of the body during tactile sensory testing

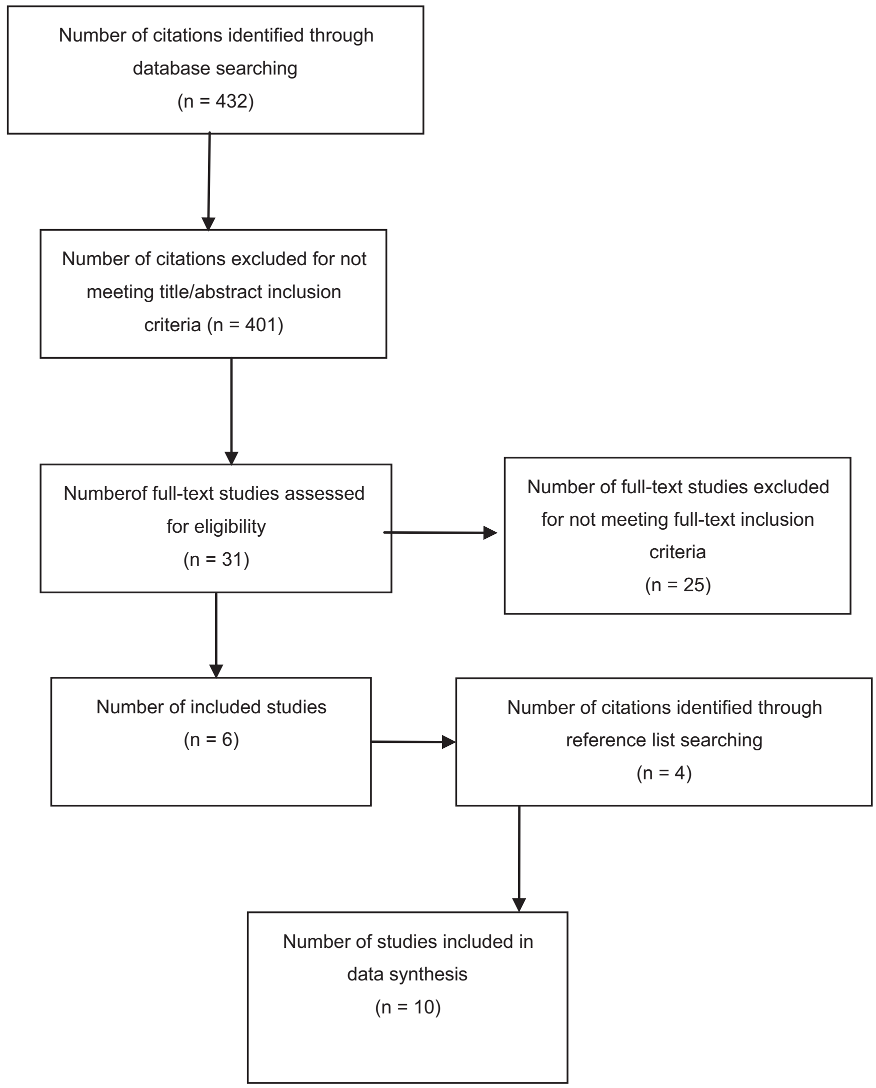

Fig. 1. Systematic search process.

the systematic search process, based on PRISMA criteria, is shown in Fig. 1.

3.2. Methodological quality

Overall, it was determined that there was a low to moderate risk of bias across all studies included in this review. Contributing to an increased risk of bias across studies was the lack of justification for the sample size in each study and the lack of reporting reliability and validity for the outcome measures used. Table 2 shows a summary of the risk of bias for each individual study across the five items.

3.3. Study characteristics

All of the 10 studies included in this review were randomized, within-subject, controlled trials, published in English. Study characteristics are presented in detail in Table 3. The included studies comprised 232 healthy participants, all undertaking tactile acuity testing. There was high heterogeneity for the specific tactile acuity tests used in each study, although all studies assessed a change in tactile acuity. Three studies performed two-point discrimination based tasks (Kennett et al., 2001; Serino et al., 2009; Catley et al., 2014); one used a two tap, vibration discrimination task (Serino et al., 2007); two used proximal/distal spatial discrimination tasks with vibro-tactile and tactile input (Press et al., 2004; Haggard et al., 2007); three used grating orientations (Taylor-Clarke et al., 2004; Cardini et al., 2011, 2012); and one used discrimination of vibration at different amplitudes (Harris et al., 2007). All studies except two included a control or comparison condition that involved viewing an object placed in the same peri-personal space as the body. That is, they used a non-body related vision control. Two studies simply concealed the body part from view, that is, they used a no vision control (Harris et al., 2007; Catley et al., 2014).

Other issues that were investigated were whether magnification of the body enhanced VET (Kennett et al., 2001), whether VET occurs at different areas of the body (Serino et al., 2009; Catley et al., 2014), and the time it takes for VET to occur (Cardini et al., 2012). In addition to this, one study (Taylor-Clarke et al., 2004) investigated the effect of a time delay between a visual and tactile stimulus; and another (Serino et al., 2007) assessed whether participants with low base levels of acuity improved at a higher rate and further tested this hypothesis in a patient population.

Table 2
Risk of bias for individual studies.

Study	Randomisation/ counterbalancing	Blinding	Complete outcome data/ selective reporting	Ethical considerations	Participant details/sampling
Kennett et al 2001	No	Yes	Unclear	No	Unclear
Press et al 2004	Yes	Unclear	Unclear	Yes	Unclear
Taylor-Clarke et al 2004	Yes	No	Unclear	Yes	Unclear
Haggard, Christakou & Serino 2007	Yes	Yes	Unclear	Yes	Unclear
Serino et al 2007	Yes	Unclear	Unclear	Yes	Yes
Harris et al 2007	No	No	Unclear	Unclear	No
Serino et al 2009	Yes	Yes	Unclear	Yes	Unclear
Cardini, Longo & Haggard 2011	Yes	Yes	Unclear	Yes	Unclear
Cardini et al 2012	Yes	Yes	Yes	Yes	Yes
Catley et al 2014	Yes	Yes	Yes	Yes	Yes

Yes (low risk of bias) Unclear (potential risk) No (high risk of bias)

3.4. Results of individual studies

Despite the diversity of testing protocols and outcome measures that were used, eight out of the 10 studies reported non-informative vision of the body as having a positive effect on tactile acuity. We were able to pool sufficiently homogenous data (similar outcome measures) to perform two meta-analyses to further investigate the significance of findings from grating orientation tasks and proximal/distal spatial discrimination tasks. We did not combine these two measures of tactile acuity as the physiological constructs underpinning the two were felt to be functionally heterogeneous (i.e. measuring sufficiently different phenomena) and this view was upheld by high statistical heterogeneity. For several studies standard deviations were not explicitly reported, so we calculated them according to the details presented in study figures, which were available for all of those studies (Taylor-Clarke et al., 2004; Cardini et al., 2011, 2012; Press et al., 2004; Haggard et al., 2007). From these extracted data, standardized mean differences were calculated.

The meta-analysis for grating orientation demonstrated a significant positive effect of vision of the body ($p=0.002$, *SMD* 3.31, 95% CI 1.24–5.39), but statistically high heterogeneity (Fig. 2) (Taylor-Clarke et al., 2004; Cardini et al., 2011, 2012).

The meta-analysis for proximal/distal spatial discrimination testing found no significant effect of vision of the body ($p=0.56$, *SMD* 0.43, 95% CI −1.01 to 1.87) (Fig. 3) (Press et al., 2004; Haggard et al., 2007).

Improved reaction times were increased with vision of the body ($M=514$ ms, *SD* 93 ms) in a single study (Press et al., 2004). Another single study (Taylor-Clarke et al., 2004) found that introducing a delay of up to ten seconds between vision and touch still resulted in a significant visual-tactile enhancement ($p\leq 0.001$), even with an overall decline in performance. Kennett et al. (2001) reported that visibility of the arm lowered tactile discrimination thresholds ($M=30$ mm, *SD* 2 mm, $p=0.04$) as compared to viewing a neutral object. When the visual input of the arm was magnified, tactile performance further improved ($M=18$ mm, $p=0.01$). Harris et al. (2007) found a significant difference between viewing the hand vs. view occluded (all four test conditions $p\leq 0.05$) and supra-threshold limits were also significantly heightened when the base vibration amplitude was 10 times the detection threshold ($p\leq 0.01$).

Serino et al. (2007) found that viewing the hand improved performance in a group identified as having lower baseline accuracy scores as compared to a group identified as having higher baseline accuracy scores ($p\leq 0.03$). Serino et al. (2007) also found that accuracy was higher when participants viewed the hand ($d=1.95$) than it was when vision was occluded. This finding was replicated in the foot ($d=2.15$, $p\leq 0.03$) and accuracy was also higher ($d=1.63$) when the foot was viewed, as compared to a neutral object ($p\leq 0.04$). Catley et al. (2014) investigated tactile acuity of the back with and without a view of the area (and variations to control for visual feedback vs. spatial attention) over a series of three experiments and concluded there was no VET phenomenon for the back.

4. Discussion

This review aimed to determine the current state of evidence as to whether non-informative vision of the body has an effect on tactile acuity in humans. The results clearly demonstrate a positive effect of vision—eight out of 10 studies reported better tactile acuity when vision of the stimulated body part was available than when it was not. Although it was difficult to pool studies with different protocols and outcome measures, where we could pool,

Table 3
Study characteristics.

Author	Paper	Population	Comparison	Outcome measures
Kennett et al. (2001)	Non-informative vision improves the spatial resolution of touch in humans	$n=10$ (age $M=27$), normal sensation	View forearm vs. view object vs. concealed	2PD (accuracy of discrimination)
Press et al. (2004)	Visual enhancement of touch in spatial body representation	$n=18$ (age 18–39, 9 F), right-handed, normal sensation	View forearm vs. view object	Spatial discrimination (accuracy of discrimination to proximal/distal), reaction times
Taylor-Clarke et al. (2004)	Persistence of visual–tactile enhancement in humans	$n=12$ (age 22–46, 6 F), normal sensation	View finger vs. view object	Gratings (accuracy of discrimination)
Haggard et al. (2007)	Viewing the body modulates tactile receptive fields	$n=10$ (age $M=23.8$, 7 F), right-handed, normal sensation/vision	View forearm vs. view object, view part vs. whole	Spatial discrimination (accuracy of discrimination to proximal/distal)
Serino et al. (2007)	Can vision of the body ameliorate impaired somatosensory function?	$n=32$ (age 20–30, 20 F), right-handed, normal sensation/vision	View forearm, vs. view object, view rubber foot	Vibration discrimination (accuracy of discrimination to one or two taps)
Harris et al. (2007)	Non-informative vision causes adaptive changes in tactile sensitivity	Exp 5. $n=5$ (2 authors and 3 naïve)	View hand vs. concealed Exp 5.	Vibration (accuracy for thresholds of vibration at different amplitudes)
Serino et al. (2009)	Seeing the hand boosts feeling on the cheek	Exp 1. $n=10$ (age 21–30, 4 F) Exp 2. $n=10$ (age 21–30, 4 F) Exp 4. $n=10$ (age 20–26, 7 F)	View hand/foot vs. concealed, view foot vs. view object Exp 1, 2 and 4	2PD (accuracy of discrimination to one or two taps)
Cardini et al. (2011)	Vision of the body modulates somatosensory intra-cortical inhibition	$n=15$ (age $M=25.5$, 8 F), right-handed, normal sensation/vision	View hand vs. view object	Grating (accuracy of discrimination threshold)
Cardini et al. (2012)	Rapid enhancement of touch from non-informative vision of the hand	$n=33$ naïve, paid (age $M=24.2$, 18 F), right-handed	View hand vs. view object	Gratings (accuracy of discrimination threshold)
Catley et al. (2014)	Show me the skin! Does seeing the back enhance tactile acuity at the back?	$n=61$ (age <35, 30 F, normal sensation	View back vs. concealed (Exp 1 and 3); vs. view touch only (Exp 2)	2PD (accuracy of discrimination)

M=mean, 2PD=Two point discrimination, F=Female, Exp=Experiment.

the result was clearly upheld, with the exception of using proximal/distal judgments as the outcome.

How might non-informative vision improve tactile acuity? One potential mechanism is that of simply attending to the stimulated area. Here, we consider attention in a manner consistent with James' (1890) early definition – "taking possession of the mind of one out of many simultaneous events" – and consider spatial attention to be the process by which one spatial location is selected for engagement over another. It seems reasonable to suggest that vision draws our attention towards the location being stimulated and this, in turn improves our acuity to stimuli delivered in that location. On the whole, our results do not support this mechanism; most studies used viewing a neutral object in the same location as the stimulated body part as a control condition and seemed to demonstrate worse performance in the object-viewing control than in the body-viewing experimental condition (Serino et al., 2007; Kennett et al., 2001; Taylor-Clarke et al., 2004; Cardini et al., 2011, 2012; Press et al., 2004; Haggard et al., 2007). That does not exclude the possibility that spatial attention also enhances tactile acuity, but it does strongly suggest that any effect is measurably smaller than that evoked by non-informative vision. One might consider that the study that compared viewing a neutral object to performing the task in darkness and found no difference between the conditions (Taylor-Clarke et al., 2004), might imply against any effect of spatial attention, but spatial attention might be equally effective in the dark if gaze direction is maintained (see also Kennett et al. (2001)).

That the VET effect simply reflects a general arousal mechanism from seeing the body is unlikely, because it seems to be positively related to how much of the body is visible (Haggard et al., 2007), and the relative magnification of the visual image – magnification improved acuity, at least in one study (Kennett et al., 2001). Specificity of, and identification with, the viewed body part also appears to be important as discussed by Serino et al. (2008). These authors found that even viewing another person's face being touched enhanced subthreshold tactile perception on the subject's own face, but that the effect was greater when they viewed the body most clearly matched to their own and greatest when they viewed their own face.

Another potential mechanism underpinning the VET effect involves the processes that underpin integration of multiple sensory modalities into a unitary sensory experience. That multisensory processing underpins the coding of peripersonal space in humans and animals is well accepted (di Pellegrino et al., 1997; Farne et al. 2005) and animal studies clearly show neurons in frontal and parietal cortex that have tactile receptive fields on the hand, with corresponding visual receptive fields in the space immediately "above" those tactile fields (Rizzolatti et al., 1997). It would seem reasonable to predict that non-informative vision may act in unison with tactile stimuli upon these bimodal visuo-tactile brain cells. Such a mechanism seems consistent with evidence that vision of the body modulates early somatosensory processing in S1 (Cardini, Longo and Haggard, 1997), and that modulation of S1 results in a reduction of the neurons' tactile field size thus enhancing acuity (Haggard et al., 2007). It is not clear, however, why the effect is more apparent at the limits of tactile performance (Press et al., 2004) – one might expect a greater VET effect on the steeper parts of the stimulus–response curve. There is evidence to suggest that this may be a behavioral threshold or floor effect and that the VET effect occurs at a neurophysiological level for all levels of activation (for example see evoked response results from Cardini et al. (2011) and Cardini et al. (2012).

If the VET effect is modulated by bimodal visuo-tactile cells, or via direct modulation of S1 neurones, or both, then one would expect it to be somatotopically specific. Relevant to this is the finding that non-informative vision of the hand improved tactile

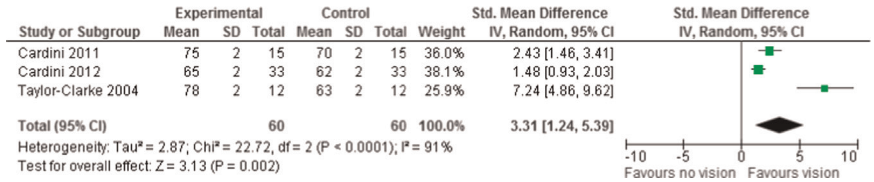

Fig. 2. Meta-analysis for grating orientation. Legend: SD – standard deviation; Std Mean Difference – expresses the size of the intervention effect in each study relative to the variability observed in that study, using the standardized mean difference allows for heterogeneity on the outcome measures; 95% CI – confidence intervals set at 95%; I^2 – this statistic denotes the degree of statistical heterogeneity across the included studies, in this figure 91% is considered high and suggests significant variance of findings across studies. The Forest Plot to the right of the figure illustrates the standardized mean and SD for each study (squares with whiskers) and the black diamond is the summary statistic of pooled SMDs (SMD with 95% CI indicated by the width of the diamond). For the individual studies and the pooled results, the confident intervals do not cross the line of "no effect" (set at "0") and therefore the result/s can considered statistically significant (with $p < 0.05$).

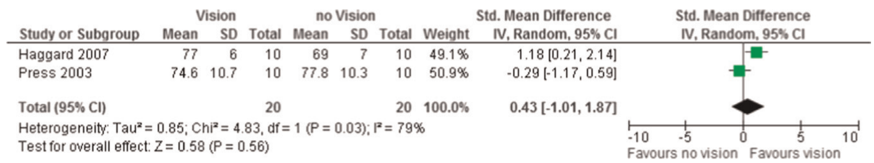

Fig. 3. Meta-analysis for spatial discrimination. Legend: As for Fig. 2. In this Forest Plot, one study has significant findings in favor of the VET (Haggard et al., 2007) whilst the second study does not (Press et al., 2003). Combined data reveals the summary statistic crossed the line of no-effect and therefore a non-significant finding is reported ($p > 0.05$). Not unsurprisingly heterogeneity is high at 79%.

acuity at the hand and the face, but not the foot (Serino et al., 2009). These authors interpreted these results to reflect the importance of the proximity in S1 of the representations of the area seen and the area touched. However, it is notable that, with respect to this proposal, the actual distance in S1 representations between the hand and face is similar to the distance between the hand and the foot, which suggests that simply proximity in S1 is unlikely to be the determinant. A more likely candidate may be related to functional relationships and the hand and mouth are clearly more closely related in that way than the hand and foot. Indeed, monkey studies have shown extensive influences within primary sensory cortex of tactile stimuli to the hand, influences that extend well beyond tactile receptive fields (Reed et al., 2008).

The VET effect might also be present for the foot (Serino et al., 2009) i.e. viewing the foot enhances tactile acuity of the foot, however Catley et al. (2014) showed there was no VET effect for the back. While there is clear and considerable evidence of bimodal visuo-tactile cells relating to tactile receptive fields at the hand, no such evidence exists for the foot, nor indeed the back. This is important because, while we often work with our hands while watching what we are doing, this is seldom the case for activities with our feet, and sensation of the back is primarily for protection not exploration. That non-human primates use their feet in this way far more than we do may suggest that this bimodal functionality remains, but further research is required to determine if this is the case. Earlier work by Tipper et al. (2001) using illusory vision, also suggested that body areas more often viewed in real life (such as the face) were more likely to demonstrate the VET effect than areas not commonly viewed (such as the neck).

The current review has a clear clinical implication. Tactile discrimination training (TDT) is used clinically to assist patients with nervous system injury or disease, such as stroke, regain tactile function and enhance quality of life (Hillier and Dunsford, 2006; Wand et al., 2014) and recent research has found it can also be useful to reduce both acute and chronic pain (Longo et al., 2012; Moseley and Wiech, 2009; Moseley et al., 2008; Serino et al., 2007; Wand et al., 2013; Wand et al., 2011; Flor et al., 2001; Moseley and Flor, 2012). Conventionally, TDT requires the patient to look away from a stimulated body part or to have vision occluded because doing so prevents the patients from seeing the stimulus and therefore ensures that they rely on touch only. However, the current review strongly suggests that this practice may be limiting the effectiveness of training. The current review implores us to develop new ways of training tactile acuity while capturing the VET effect. Our group has experimented along these lines and observed encouraging effects. For example, TDT using a mirror to provide non-informative vision of what looks like the stimulated arm, but is in fact a mirror reflection of its counterpart, improves the effect of training on tactile acuity and pain for at least 48 h in adults with complex regional pain syndrome (Moseley and Wiech, 2009). The improvement in tactile acuity was measurably greater than that observed with vision occluded (Moseley et al., 2008). See Ro et al. (2004) for earlier reports on the use of illusory vision for tactile perception and involvement of the parietal cortex. Finally, capturing this VET effect via illusory touch improves tactile function in areas of persistent sensory loss after peripheral nerve injury (Wand et al., 2014).

These possibilities are reinforced by the finding in one study in this review – that people with lower baseline acuity had more significant improvements in tactile acuity when vision was available than those with higher baseline acuity (Serino et al., 2007). The current review underpins these recent discoveries by offering a fundamental mechanism by which the inclusion of vision might enhance a training effect.

Although the vast majority of studies showed positive effects from vision, many studies had methodological issues that should be remembered when we interpret their results. The risk of false positives was elevated because, remarkably, no study established their sample size a priori, even though for many there were sufficient data in the literature to do so, and many undertook multiple analyses without adjusting their significance. Most of the studies reported the participants as having normal visual and tactile sense, but no study explicitly stated baseline measures or whether normality was assessed by any means other than participants giving verbal assertion. The reliability and validity of outcome measures used were not reported in any of the studies. A recent evaluation of the reliability of a common measure of tactile acuity – the two point discrimination threshold – raises doubt over the measure (Catley et al., 2013) and suggests that equally rigorous interrogation of other commonly used measures of tactile acuity is warranted.

With respect to our review and meta-analysis, it should also be noted that although efforts were made to identify all relevant evidence, through a systematic search of different databases and pearling of reference lists, studies of interest could have been missed. For practical reasons, only one reviewer was involved in the initial search and abstract selection, and the search strategy excluded non-English language papers. Studies that used illusion or reflected images of the body were also excluded, in order to minimize methodological heterogeneity, but may have meant we missed studies that do in fact engage the VET effect. We contend that this is probably not of high impact for our results because those of which we are aware appear supportive (Moseley and Wiech, 2009). But, nonetheless, we cannot be sure without applying a systematic search. This points to a relative strength of our review over narrative reviews of this area, which are common. In particular, selection bias is considered a major limitation of narrative reviews and we overcame this risk by establishing a priori (and subsequently adhering to) our search strategy, inclusion and exclusion criteria, data extraction protocol and analytical approach, according to recommended best practice (Higgins et al., 2011).

5. Conclusion

This review aimed to determine the current state of evidence as to whether non-informative vision of the body has an effect on tactile acuity in humans. The results clearly demonstrate a positive effect of vision – eight out of 10 studies reported better tactile acuity when vision of the stimulated body part was available than when it was not. Of particular interest is the discovery that participants with low baseline tactile discrimination measures benefitted more from non-informative vision of the body than those with high baseline discrimination, which suggests that the effects of sensory training might be enhanced by incorporating vision and thus exploiting the VET effect.

Conflict of interest

There is no commercial or other conflict of interest of the authors relevant to the subject of the manuscript. GLM is co-author on one included paper but was not involved in the appraisal of that paper.

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