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The Kinaesthetic Fusion Effect: Fast-forward 30 Years

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This study investigated the Kinaesthetic Fusion Effect (KFE) first described by Craske and Kenny in 1981. The current study did not replicate these findings following a change in the reporting method used by participants. Participants did not perceive any reduction in the sagittal separation of a button pressed by the index finger of one arm and a probe touching the other, following repeated exposure to the tactile stimuli present on both unseen arms. This study's failure to replicate the widely-cited KFE as described by Craske et al. (1984) suggests that it may be contingent on several aspects of visual information, especially the availability of a specific visual reference, the role of instructions regarding gaze direction, and the potential use of a line of sight strategy when referring felt positions to an interposed surface. In addition, a foreshortening effect was found; this may result from a line-of-sight judgment and represent a feature of the reporting method used. Finally, this research will benefit future studies that require participants to report the perceived locations of the unseen limbs.

Occasionally, information mediated by relevant sensory receptors can be misleading, such as when two sensory systems provide different information about the same event, and perceptual mis-judgements can result. A prominent example includes the Ventriloquist Illusion - the incorrect localisation of a sound as coming from the visually observed location of a person's moving lips when it is actually spatially displaced (Bertelson, 1999).

Craske and Kenny (1981) described one specific sensory conflict between the tactile and proprioceptive senses which resulted in a sensory illusion, which they labelled the Kinaesthetic Fusion Effect (KFE). They reported that when, without vision, participants repeatedly pressed a button that resulted in a probe simultaneously touching the contralateral limb at a sagittally displaced location (the axis which passes horizontally from front (distal) to rear (proximal)), they reported a much decreased sagittal separation of these two locations. The authors interpreted this as a change in perceived limb length by the participants. (Craske & Kenny, 1981, 1984). To date, no study has replicated or extended the Craske et al (1981, 1984) findings.

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These results have frequently been taken at face value. For example, McDonnell, Scott, Dickison, Theriault, and Wood (1989, p. 18), stated that “These authors have demonstrated a significant adjustment in perceived limb length following exposure to discordant sensory information.” More recently, Ehrsson, Holmes and Passingham (2005, p. 10569), in reporting that the rubber hand illusion can occur without the use of visual feedback, specifically cite these reports of the KFE as evidence that “synchronous tactile stimuli on two body parts can cause illusory distortions in size, shape and location of body parts.” Indeed, these papers continue to be cited (e.g. Longo & Haggard, 2010; and Schmalzl & Ehrsson, 2011, p.9, who state that Craske and Kenny’s findings are evidence that “perceived arm length can be experimentally manipulated through discordant tactile input to both arms”).

Given that the KFE has continued to be cited after more than 30 years as evidence for changes in perceived limb length resulting from such discordances, as well as a basis for the exploration of similar illusions, it is surprising that there has been no study attempting to replicate the original effect. Furthermore, examination of the methods used in these studies reveals several potential weaknesses. Of these, the most important is the use of a purely subjective position estimation method. Participants had to report the position of the probed location on one limb relative to the index finger of the other, by giving a verbal estimate of its size, in inches. Not only is this estimate not objective, it is quite unclear whether it under- or over-represents actual distances, or whether it is linear, consistent over time or at different locations along the limb. Secondly, their conclusion that the KFE represents a change in perceived limb *length* rather than a perceived limb *position* change (with perceived length remaining constant) is weak. This is because drawing this distinction requires the perceived position of at least two locations on the limb to be reported. They undertook such a comparison in only a single follow-up experiment, and the comparison involved only one of the two limbs, and was made between participants in two distinct groups. Moreover, the only data supplied is the difference between experimental and control conditions, so only relative position data is available. Thirdly, the same location was probed on many consecutive trials, reducing the probability that truly independent judgments were made for each. A fourth weakness was that no baseline data were collected (i.e. prior to the control or displaced probe conditions), so that any displacements cannot be unambiguously attributed to the treatment. Finally, a fifth and a sixth shortcoming of their design were the absence of counterbalancing of displaced probe and non-displaced probe conditions, the comparison of which was the basis for inferring the KFE, and the absence of any measurement of the perceived mediolateral position, which would have enabled a two-dimensional description of any resulting illusions. There is no reason to suppose that the KFE should be a purely one-dimensional effect.

In order to provide a more rigorous evaluation of this proposed illusion the following changes and additions were undertaken. A baseline condition was included; a visual reporting reference grid was positioned above the unseen arms which not only allowed position estimates to be made with respect to a known reference frame rather than through subjective reporting, but also allowed sagittal and medio-lateral positions to be recorded. We also measured the perceived position of ten locations on each arm. If any KFE were to involve equal displacements of all positions, this would more clearly establish that the effect involves a perception of altered limb *position* rather than one of altered *length*, which would be evident in a proportionately scaled change in these perceived locations. The final modifications to the original experimental procedure were the randomization of the order of touched arm locations (to encourage independent judgements on each trial) and the counterbalancing of control and experimental conditions.

METHOD

Participants

Participants were recruited from Queensland University of Technology. Sixteen individuals participated (9 male, 7 female). All participants participated voluntarily and were not reimbursed. Participant ages ranged from 19 to 32, mean 24.2 years. 13 participants were right handed. Participants had no prior experience with tactile or proprioceptive experiments. Participants who did not state any relevant, sensory, motor or cognitive medical conditions that might affect their ability to participate in the experiment were included. Participants were not informed of the expected results or hypotheses. The Queensland University of Technology Human Research Ethics Committee approved the study and written informed consent was obtained from all participants prior to data collection.

Apparatus

Participants sat in a chair at a desk. A wooden surface was secured in place at a height 15cm above the desk surface. This arrangement allowed the participants to rest their arms on the desk but with all visual information about limb positions occluded throughout the experiment. A box surrounding the surface, open at the end where the participant sat, allowed viewing of a grid above the arms but prevented the participant from gaining location cues when the examiner touched the limbs in later parts of the experiment.. A grid covered the entire surface and contained approximately 2200 squares (0.96cm x 0.98cm). In each square, a code consisting of a letter followed by two numbers allowed participants to report the square they perceived to be directly above the touched position on their arm by stating the relevant code. The grid codes were spatially randomised to decrease the likelihood of participants using memory strategies when making location judgments and to prevent inferring a position by extrapolation from neighbouring positions. Participant reports of grid codes were converted to spatial coordinates with a computer look-up function. The arms rested in wedge-shaped foam support that allowed them to remain in the same position throughout the experiment. The foam also permitted the right index finger to rest horizontally next to a button that was located medial to the right arm. The arms were in a position half way between supination and pronation and the elbow angle was approximately 100 degrees. The button and probe were connected to a thin metal tube that was positioned between the participant's arms. Participants wore headphones through which a high-pitched tone masked the sound of the solenoid probe activation. This prevented the use of auditory location cues.

Procedure for Experiment Setup

Participants wore a blindfold as the examiner measured the arm length from the index finger tip to the elbow crease with a standard tape measure. Five marks were made on each participant's arm equivalent to 0, 20, 40, 60 and 80% of the arm length. 0% corresponded to the most distal aspect of the index finger. Once participants were seated at the desk they were instructed to completely relax both arms by their sides while the experimenter passively moved each limb into the foam arm support located below the visual reference grid.

Experimental instructions included informing the participants that they would be required to estimate where they were touched on either the left or right upper extremity in relation to the grid above their arms. They were explicitly instructed to choose a square by indicating the code that they believed was directly above the touched position. Participants were instructed to look in the direction of each touched location in order to facilitate their judgements. The examiner also stated that the participant should treat each judgement in relation to the visual reference grid as independent from preceding judgements in order to discourage anchoring to previous locations.

Procedure for testing

Participants were tested under three conditions. *Baseline*, (which preceded any use of the solenoid probe – see below), and two conditions during which the participants activated the solenoid probe with the right index finger to contact a location on the contralateral limb - *Undisplaced* (in which the Button and Probe were directly opposite each other, and *Displaced* in which the Button was activated in the same location as for *Undisplaced*, but the Probe contacted the left limb at a point 12.7cm closer to the body, near the left wrist). To control for any order effect the *Undisplaced* and *Displaced* condition order was counterbalanced across the 16 participants.

During the *Baseline* measurements, the examiner lightly touched the participant on one of the five positions on either arm with a wooden dowel approximately 0.5cm in diameter. The participant's task was then to report where they felt the touch in relation to the grid. The solenoid probe device was not used at any time during this condition. The order in which the five positions on both arms were touched had been randomised prior to the experiment for each participant, to minimise any memory-based judgments or simple repetition of any grid code. Each position was touched three times in total in each condition. The examiner kept the dowel on the touched position until the participant provided a response, so that memory-based judgments were not required.

Following the baseline condition, the participant was either assigned to the group that undertook the *Undisplaced* condition or *Displaced* condition first. In each condition, the participant was instructed to press the button by slightly flexing the right index finger. After pressing the button 10 times sequentially with a gap of one to two seconds between presses, the participant was instructed to report where they felt they were pressing the button and where they felt the probe touch the left arm in relation to the grid. This process continued for another five trials and the button was pressed a total of 60 times. This constituted one block. Having completed one block, the examiner asked the participant to cease pressing the button while the 10 locations on both arms were passively touched (this process will be known as the 'passive touch task' and was conducted in both *Displaced* and *Undisplaced* conditions immediately after each set of active probe trials). Again, the participant's task was to report where they now felt the touch. Once each position was touched and an estimate recorded, the participant was instructed to press the button another 10 times, until another block was complete. In total there were three blocks for each condition.

Data Analysis

A repeated measures analysis of variance (ANOVA) with the fixed factors arm, condition, trial and position was used for statistical analysis. *T*-tests were used when only two values were compared. Bonferroni or LSD post hoc tests were used. Where applicable, sphericity was not assumed and analysis was undertaken using the Greenhouse-Geisser adjustment. An alpha level of .05 was used for all statistical tests.

RESULTS

The "Foreshortening" Effect

Before presenting the main results that bear on the question of the KFE, results pertaining to an important aspect of the reporting method will be outlined. Figure 1 shows a large and systematic shift – towards the body of all reported positions relative to their actual locations, and medially for all but the fingertips.

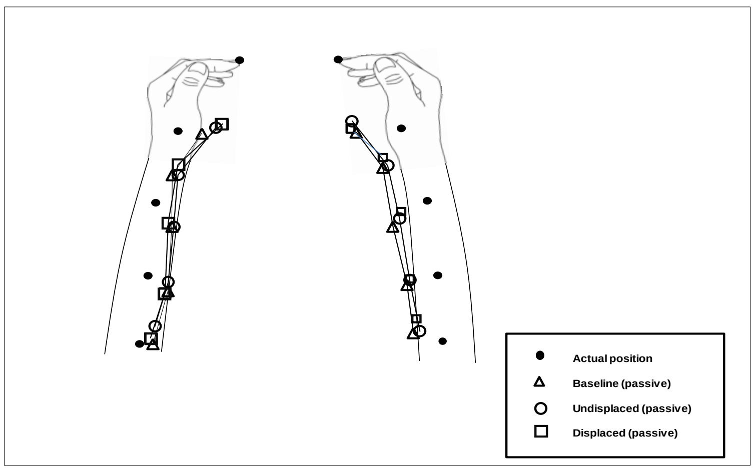

FIGURE 1 The actual touched position and the mean reported positions in Baseline, Undisplaced & Displaced conditions for 0, 20, 40 60, 80% of arm length positions only. Exact limb configuration varies between participants. Arm representation is indicative.

If taken at face value, this would indicate that there were substantial shifts towards the body and mostly medially in the perceived overall locations of the two limbs at all stages of the experiment. However, an aspect of the reporting method may account for this apparent shift. Figure 2 shows the relationship between the sagittal locations of the index fingertip resting on the surface (Y1 in Figure 2), and its projection along the line of sight to the surface, of the reporting grid). If participants made their judgments about any limb location by a "visual" line of sight judgment (that is, directing gaze towards this location and selecting the grid code on that line of sight), then the reported position on the grid would correspond to a "foreshortened" position (shown by Y2 in Figure 2).

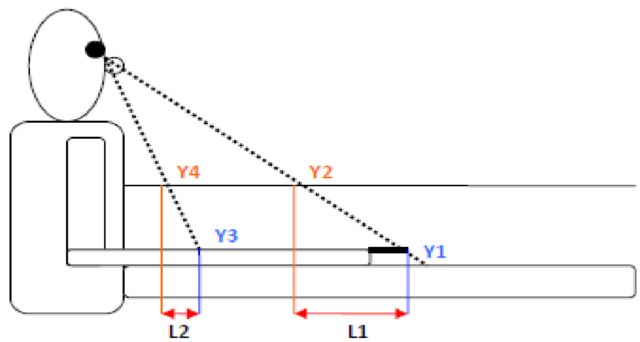

FIGURE 2 The Foreshortening Effect (sagittal plane) Which Demonstrates the line of Sight Position on an Interposed Surface Between the Touched Limb Position and the Eye

To test this possibility, the typical three-dimensional position of the participant's head (midway between each eye) was estimated. The known average actual positions touched during the experiment (0, 20…80% positions) were then expressed in adjusted sagittal and medio-lateral coordinates (that is, by their projection along this notional line of sight). Also taken into account was the height of these positions relative to each surface, due to the nonsymmetrical nature of the limb, which resulted in the touched positions all being somewhat higher than the desk-top, and less than 15cm beneath the reporting grid.

A linear regression was calculated to establish a linear relation between the reported and transformed line of sight data. These transformed line of sight data were regressed against the reported values, resulting in a slope of 1.14 (right arm) and 1.11 (left arm), and an intercept of -5.35 cm (right arm) and -4.51 cm (left arm), $r > 0.999$ (right arm) and $r > 0.997$ (left arm). This indicates a near linear scaling, consistent with the participant's reporting the code for the grid square lying on the line of sight to each touched location.

In theory, positions closer to the body should have less foreshortening in the sagittal plane as shown in figure 2; that is, L1 should be greater than L2. This directional prediction was confirmed by comparison of constant error (actual–reported) between the five positions on each arm using a one way repeated measure ANOVA. There was a significant difference between the five positions for the left, F (4, 60) = 9.23, p <.001 and right arms, F (2.34, 17.26) = 12.30, p<.001. Post - hoc tests revealed there were significant differences between all comparisons except for between 20% and 40% and 40% and 60% for the right arm. For the left arm only when comparing 40% and 80%, and 60% and 80%, were there no significant differences. A foreshortening effect is present where positions further from the shoulder are reported by the participants as successively and significantly closer to the body than the actual position (Figure 2). This serves to illustrate that positions closer to the body resulted in less foreshortening error in the sagittal plane and that the data follow the logic of a foreshortening effect (Figure 2), and is considered in the discussion. All subsequent data presented will use the *reported* positions foreshortening is therefore not a factor in subsequent comparisons.

The KFE

To determine if a KFE occurred as described in Craske et al (1984), two analyses were undertaken. The first used an approach similar to that reported by Craske et al (1984); namely, the analysis of changes in perceived position of the button and the probe over trials during active button pressing. The logic of this comparison is that if a KFE is induced in the *Displaced* condition, the perceived positions of the button and the probed location should converge over trials. Any KFE (i.e. limb position or limb length change) would be evident in this analysis. In addition, the current experiment allowed a second test for a KFE. If such an effect was evident and extended to all parts of the limb, it would be expected that, on touching the limbs immediately after the *Displaced* condition (passive touch condition), participants would report a shift of one or more of the touched limb locations in the sagittal plane. This could be either a constant shift of all locations, indicative of an altered sense of limb position, or a proportional shift, suggesting a change in limb length perception.

The results showed that although the position of the probe was perceived to move gradually slightly closer to the button there was no significant change over trials F = (2.04, 30.64) 1.51, p>.05, d = .06. On the other hand the button, which had been described as moving closer to the body in the experiments by Craske et al (1984), moves slightly but non-significantly further from the body F = (4.85, 72.86) 1.31, p>0.05, d=0.04. Overall, there was no KFE as described previously. Furthermore, the second analyses showed that there were no significant differences in the perceived positions between conditions after the passive touch by the examiner for either arm F (2.62, 39.40) = 0.95, p> .05, d=.04.

DISCUSSION

The KFE, as described by Craske et al (1984) and assessed by two analyses, was not replicated in this study following a change in the reporting method used by participants. There was no change in perceived limb length or limb position in the sagittal plane. The absence of this effect requires some consideration of each of the ways in which the current study differs methodologically from the original investigations, in order to identify possible reasons for the discrepancy.

Intersensory judgement

The judgements made by our participants were different from those of Craske et al. (1981), which were essentially intrasensory because all vision was occluded by a blindfold. Our reporting method explicitly required vision to enable the reporting of a touched position and this combining of tactile and visual mapping meant that these judgments were intersensory. This may account for the different outcomes if localisation is significantly more accurate than judgements made using an intrasensory mental model (tactile-only). Specifically, the availability of vision may attenuate the "illusory" aspect of the KFE. Evidence for this interpretation comes from a report by Craske et al, (1984), p.311, of a subsequent experiment in which participants made their judgments relative to a light directly above the touched position, and in which the relative KFE was substantially reduced. Indeed, the authors themselves noted "the visual/tactile discordance was more powerful than the tactile," by which they meant that the KFE was reduced as participants became aware of the discrepancy between the reference light and the felt position. Moreover, at the end of their second paper (Craske et al, 1984) they observed that when participants were asked to move the arm so as to place the index finger underneath a point of light (using a visual-proprioceptive judgement) following their standard displaced probe manipulation, they showed no evidence of the KFE.

A number of other studies (Haggard, Newman, Blundell and Andrew, 2000; Van Beers, Sittig, and Denier van der Gon, 1998; Von Hofsten and Rosblad, 1988; Wann 1991) have also shown that accuracy was superior during an intersensory judgement task compared to that of an intramodal task. Typically, participants in these studies look at a visual reference position and then locate that position with the unseen limb (visual-proprioception condition). This tends to be more accurate than a corresponding proprioceptive condition in which the other limb provides the position reference.

Newport, Hindle and Jackson (2001) showed in a stroke patient that actively viewing the workspace adjacent to the felt position of the unseen somatosensory impaired hand substantially aided the localization of the impaired limb when pointing to it with the nonimpaired limb**.** They speculated "that vision of the workspace may act to boost somatosensory signals indicating limb position….The novel finding in our report is that *vision of the workspace adjacent to the unseen limb* may be sufficient to boost somatosensory information signaling the position of the unseen limb" (p.979). A comparable enhancement of somatosensory input may also occur in healthy individuals when locating the unseen limb.

Foreshortening effect

After calculation of the projected line of sight between the eyes and each touched position onto the grid surface, a high correlation with an intercept close to zero and a slope close to one was found between the reported positions and the positions that lie on the line of sight. Therefore, although the participants were instructed to report the grid code that lay directly above the touched position, the majority of individuals chose a position along a line between the eye and the touched position. Here it is proposed the participants had a predisposition to choose a position along the line of sight. Just such a process could also explain the data of Gross, Webb and Melzack (1974), who reported a systematic foreshortening of the positions of the fingers, hand and wrist in an experimental setup almost identical to the study described here, interpreting this as a real perception of limb shortening resembling phantom limb phenomena. Indeed, there is evidence for the reliance on the angular declination from the eye to a target for distance judgments (Ooi, Wu and He, 2001). Gross et al, (1974) did not discuss the possibility that their results might reflect a measurement artifact created by this 'line of sight' position judgment, rather than a true perceptual change. Future studies should recognise this as a possible mode of responding, and investigate the circumstances in which it occurs.

In conclusion, this study's failure to replicate the widely-cited KFE as described by Craske et al, (1984) suggests that it may be contingent on several aspects of visual information, especially the availability of a specific visual reference, the role of instructions regarding gaze direction, and the potential use of a line of sight strategy when referring felt positions to an interposed surface. In addition, a foreshortening effect was found; this may result from a line-of-sight judgment and represent a feature of the reporting method used. Finally, this research will benefit future studies that require participants to report the perceived locations of the unseen limbs.

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