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RESEARCH ARTICLE

Visual-proprioceptive mismatch and the Taylor illusion

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Abstract When a participant moves a hand-held target in complete darkness after an afterimage of that target has been obtained, an illusory increase (with movements away from the participant) or decrease (with movements towards the participant) in the apparent size of the afterimage is reported (the Taylor illusion, reported first in Taylor, J Exp Psychol 29: 1941). Unlike typical Emmert's Law demonstrations, the Taylor illusion shows that a motor-related signal can be used to specify distance for the computation of real size. A study by Carey and Allan (Exp Brain Res 110: 1996) found that the Taylor illusion did not occur in a condition where an afterimage of one hand was obtained while the other hand performed a movement away from the participant from directly behind the first. It was proposed that, for the illusion to manifest itself, proprioceptive and visual information must be in strict "register" when the afterimage is obtained. To evaluate this hypothesis, 14 participants performed "towards" and "away" movements after obtaining afterimages of hand-held cards. Participants wore either plain lenses or prism lenses during the trials, the latter of which displaced visual stimuli 10° to the left. No significant difference was found between the two lens conditions in terms of the effect on the perception of the Taylor illusion. It was concluded that the illusory size distortions may depend on register of visual and proprioceptive position in terms of depth, rather than in the picture plane. Several suggestions for future studies of the Taylor illusion are proposed, and limitations of size judgements of afterimages are outlined.

Keywords Proprioception · Illusion · Size constancy · Emmert's law

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Introduction

The visual system is capable of determining whether changes in retinal image size are due to changes in target distance or in those rare instances when the changes are in the actual physical size of the target. An extremely reliable demonstration of this size-distance scaling process was reported by Emmert (1881). An afterimage is perceived to be smaller in cases where a more proximal visual plane is fixated, and larger when a more distant projection plane is fixated. This phenomenon clearly demonstrates that the size-distance scaling mechanism can, in unusual circumstances, manifest itself: although the retinal image (the afterimage) does not change in size, when a change in the distance of the projection plane occurs, the participant perceives a change in size where none has taken place (for reviews of Emmert's law and related phenomena, see Carey and Allan 1996; Hershenson 1989).

Experiments based on this illusion (Taylor 1941; Gregory et al. 1959) have assessed the extent to which size-distance invariance is dependent purely upon visual information. Participants looked at afterimages of either hand-held cards, or of the hand itself, in total darkness. Immediately after obtaining a positive afterimage (produced by a powerful light source), participants moved the target object either towards or away from themselves. With no visual source from which to determine any change in the distance of the viewing plane, participants still perceived size changes (in the direction predicted by Emmert's Law) in the afterimages. These results clearly suggest that information related to movement can be a factor in the perception of relative size and/or distance. These "non-visual" Emmert's-like demonstrations have been collectively referred to as "the Taylor illusion" by Carey and Allan (1996).

An examination of the actual nature of the motor information required to drive the Taylor illusion was carried out by Carey and Allan (1996). Two types of movement, "active" (which involved participants producing either towards or away movements independently) and "passive" (which involved the experimenter moving the participant's hand in the appropriate direction), were compared in terms of the extent to which they produced the Taylor illusion. No significant difference was found between the two movement types, both of which produced the Taylor illusion reliably (see also Bross 2000). It was concluded that corollary discharge (or "efference copy" Matin 1976; Bridgeman 1995) was not necessary, and that changes in proprioceptive feedback were at least sufficient for the generation of the illusion.

One difficulty with Carey and Allan's (1996) original experiment was the rather crude means used to estimate magnitude of size change; participants were asked to report the percentage change in the afterimage relative to the perceived size of the afterimage before the hand was actively or passively moved (see Carey and Allan 1996 for a more detailed discussion). In a later study on the Taylor illusion (Mon-Williams et al. 1997), designed to look at the relationship between vergence eye movements and the illusion, participants described the magnitude of size change by opening their hands to a degree indicative of the perceived size change of the afterimage; the magnitude of hand opening was recorded with an opto-electronic motion analysis system. While such a procedure does indeed provide data on an interval scale, in our laboratories virtually all subjects agree that making absolute size (or absolute distance) judgments of afterimages viewed in complete darkness is extremely difficult. Such reports are unsurprising, given the absence of any other visual texture and any sense of a projection plane when viewing afterimages (readers are encouraged to "see" for themselves). Therefore, we suspect that the participants in the Mon-Williams et al. (1997) experiments were using their hands to indicate relative size change (i.e., from a "little bit bigger" to a "whole lot larger" and so on) as opposed to the absolute size of the afterimage itself.

In psychophysical studies of visual perception, a number of magnitude estimation procedures have been used to examine relative size judgements such as these; consequently, one possible procedure was explored in the present study. An additional advantage of a more controlled measurement of the size of the illusion on a trial-by-trial basis is that it would allow the magnitude of the illusion in "away" and "towards" conditions to be compared in a more rigorous fashion. Carey and Allan's (1996) suggestion that the magnitude of the perceived size change is indeed larger for away rather than towards movements needs careful evaluation.

Vision of the limb is particularly important for visual-proprioceptive binding in humans (i.e., Newport et al. 2001). A third type of trial carried out by Carey and Allan (1996) examined whether or not afterimages in an essentially "correct" two-dimensional position on the retina could be erroneously mapped to the target that was subsequently moved (their "non-dominant hand condition"). Participants placed one hand directly behind the other and, upon obtaining an afterimage of the nearer hand, moved the "obscured" hand away from themselves (of course, neither hand was actually visible after the flash per se). The effect of the Taylor illusion was very infrequently reported (1/26) under these conditions. It was concluded, therefore, that the movement necessary to drive the Taylor illusion must be made with the same hand from which the afterimage was obtained. Carey and Allan (1996) proposed a number of explanations for this result, including one suggested by the work of Davies (1973); namely, that there might need to exist some form of register between visual and proprioceptive information regarding the target object's position before the Taylor illusion can be perceived (a similar registration of felt and seen hands seems to be necessary for the amelioration of visual extinction in the patients of di Pellegrino and Fassinetti 2000). There was no such exact match in Carey and Allan's (1996) non-dominant hand condition; the hand that was moved was not the source of the afterimage, consequently no Taylor illusion was perceived. To examine this hypothesis, it is essential that the disruption of the match between visual and proprioceptive information be examined in a different way.

The displacement of vision through use of prism goggles offers an attractive alternative method of disrupting the correspondence between visual and proprioceptive information related to hand position. An additional benefit of our procedure is the removal of the shape cues (i.e., a left hand or a right hand) and occlusion produced in the Carey and Allan (1996) non-dominant hand trials. If it is indeed the case that the subtle "mismatch" between visual and proprioceptive information regarding the target object's position in Carey and Allan's (1996) non-dominant hand condition was responsible for the failure of the Taylor illusion, then the gross mismatch of these position signals when prism goggles are worn should null the illusion even more completely.

The final issue addressed by the present study was assessed with an important control condition that has been omitted in previous demonstrations of the Taylor illusion: static trials. The introduction of trials which created afterimages in the same conditions as active trials, but required no movement by participants, allowed the reliability of reported size changes on ordinary Taylor illusion trials to be examined.

Materials and methods

Participants

All procedures were vetted by the School of Psychology's ethics committee which uses the British Psychological Society's Ethical guidelines and the World Medical Association Declaration of Helsinki. Of the 14 participants who took part in this experiment (all of whom were unpaid volunteers who gave their informed consent) seven were male and seven female. All of the participants were university undergraduates and were right-handed. The age of participants ranged from 18–24 years.

Materials

The main piece of apparatus used featured a chin rest and two wooden dowels (see Carey and Allan 1996 for additional details). These dowels were placed at eye level at respective distances of 22 and 42 cm from the participant's eye when the participant was positioned in the chin rest. A chair of adjustable height was used to make allowance for the variability of participant height. A background board, measuring 2 m in breadth, was placed at a distance of 2 m in front of the participant when positioned in the chin rest. This board was covered with black canvas and a dimmed red light-emitting diode (LED) was positioned directly ahead of the participant at eye-level and aligned with the centre of the hand when placed at either dowel. A camera flash was used to produce the afterimages. Two pairs of goggles (one containing plain glass, the other containing prism lenses that displaced the image 10° to the left) were worn by the participants. The goggles were identical in shape and weight.

Stimuli for the size ratings

Each of seven training cards, all of which were square, represented one point on a size rating scale running from 1 to 7 (see Fig. 1). Point 4, the midpoint of the scale, measured 8.7 cm in edge-length. Point 7 was twice this value in edge-length, while point 1 was half. Points 2, 3 and points 5, 6 were placed, in terms of edge-length, at regular intervals between points 1, 4 and points 4, 7 respectively (making the edge-length increases between points below point 4 half the size of those increases beyond point 4).

The two experimental cards, which were also square, were of 6 and 11.45 cm in edge-length. These sizes were chosen so that at their respective starting positions in the experiment (the dowel at 22 cm for the small card and the dowel at 42 cm for the larger card) both cards would subtend the same visual angle, of 15.2°, on the retina. The training card representing point 4 on the rating scale also produced this same retinal angle when placed at 32 cm, the distance at which training was carried out which was at the midpoint of the workspace with respect to the two starting points. On the assumption that participants are able to make

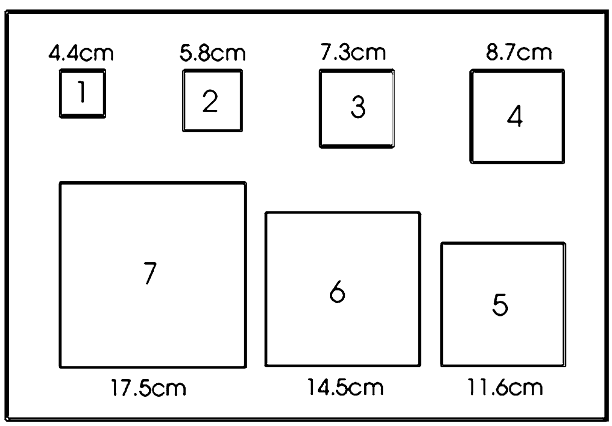

Fig. 1 Schematic of the stimuli used in the training phase for magnitude estimation training. White on black depictions of these rectangles were presented in visible light at the midpoint between the near and far starting positions

reliable size judgements based purely upon the retinal angle subtended, it was expected that the majority of initial afterimages would be rated as point 4 on the scale.

Procedure

There were two main parts to this study: the training session and the actual Taylor illusion trials. The training session was carried out under normal lighting conditions. The training cards were presented at a distance of 32 cm from the participant, who was positioned in the chin rest. On each presentation, the participant was informed of the card's position on the rating scale (from 1 to 7). Between each presentation, participants closed their eyes. Each of the seven stimuli was presented twice. Participants were then tested on their ability to identify points on the rating scale from a random presentation of two sets of the training stimuli. If a success rate of 80% (11 correct judgements out of 14 presentations) was achieved or exceeded, the participant was judged to have learned the scale adequately. In the event that this criterion was not attained, the process of training and testing was repeated fully.

Following training, participants were placed in total darkness for a period of five minutes, to allow some dark adaptation to occur. At this stage participants were given a black glove to wear on the right hand, to minimise the hand's appearance as part of the afterimage during Taylor trials. From this point forward, save for the trials themselves, participants were required to keep their eyes closed in order to avoid any incident light produced by experimenter activity. During the period of dark adaptation, participants were informed of the procedure to be followed during each trial.

On each trial, participants wore one of the two pairs of goggles (it should be noted that participants were not informed of either the quantity or nature of the pairs of goggles used and were required to place the goggles on their heads with eyes closed) and held one of the experimental cards between the thumb and fingertips of the right hand, along the bottom right-side edge. Participants were informed of the required direction of movement and starting position: for "away" trials, participants held the small card at the near dowel; for "towards" trials, participants held the larger card at the distant dowel (see Carey and Allan 1996 for details). Participants were then instructed to open their eyes and to look at the centrally-positioned dim red LED placed on a wall 2 m beyond the testing table surface. This procedure was used to ensure that the participants gaze was directed towards the position of the hand held-card when placed at the near or far dowel. (Off-visual axis afterimages produce poor illusions, largely due to futile attempts to centre the afterimage which leads to substantial gaze deviations.) Participants then placed the hand-held card in the position appropriate to the trial-type, while maintaining gaze, and positioned their right hand against the appropriate dowel so that the card obscured the LED. This procedure also served to minimise cues to the displacing properties of the one pair of goggles: if participants felt they were looking towards the hand-held card, based on position sense, and subsequently the afterimage was displaced to the right, they would be cued to the fact that they were wearing prism goggles. In spite of the possibility of some opportunity to note visual-proprioceptive mismatch when the hand was thus placed, no participant ever commented on noticing anything unusual on prism trials. In addition, during debriefing all of the participants claimed that they could not tell any difference between trials. Unlike in standard prism adaptation experiments, the participants get little visual "reafference" about their movements as all that happened was that a distant red LED was occluded by the hand held card, on every trial with prism and normal goggles. The following afterimage was central in all participants, given that they first fixated the red LED.

Participants were then given a short countdown, after which the camera flash was activated just above the participant's head, directly towards the experimental card. Participants were required to wait for a strong, positive afterimage of the card to form and, when that occurred, to make the appropriate towards or away movement at steady pace such that the movement was completed before the afterimage faded. Participants were then asked to rate, on the scale learned in the training session, both the initial and the final perceived size of the afterimage obtained. For each trial a size-change score was calculated by subtracting the initial rating of afterimage size rating from the final afterimage size rating. Positive difference scores thus indicate an increase in the perceived size of the afterimage, whereas negative scores indicate a decrease in perceived afterimage size. After each trial, participants were given as much time as was necessary for the afterimage to fade before proceeding to the next trial. Eight such trials were performed in both hand directions and, of these, half were performed while wearing plain lenses and half were performed while wearing prism lenses.

In addition to these 16 trials, 4 control trials were included in this experiment, appearing on every fifth trial. These control trials involved participants following exactly the same procedure as previously outlined, only differing once the afterimage had been obtained: participants performed no movement whatsoever of the card. Participants were required to make the final image size rating after a period of time roughly equivalent to their average movement completion time in dynamic trials. This control was to ensure that any reported size change reported in the main trials was not simply the misinterpretation of blurring or disappearance of the afterimage [a control that was not included in Carey and Allan's (1996) report]. Two "static" trials were carried out at both dowels, while one trial in each case was performed using prism goggles and the other was performed using normal goggles. At the end of the experiment, participants were asked a brief series of questions related to the number of pairs of goggles used and the frequency with which they were used.

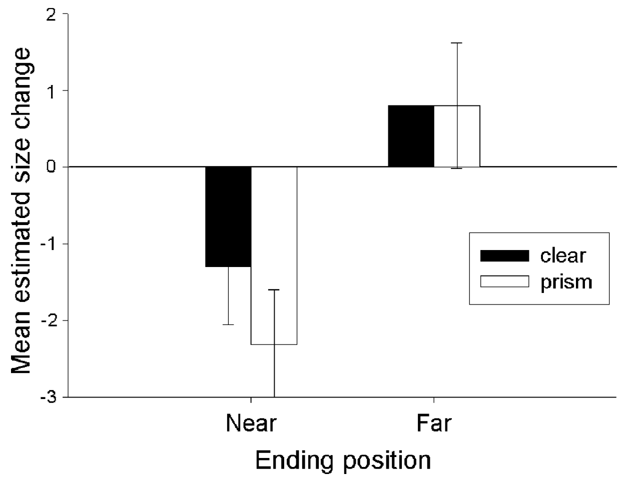

Fig. 2 Mean size change ratings for the moving trials as a function of ending position and glasses type. A negative score indicates a decrease in perceived size from the start to the end of the trial. Error bars = standard error of the mean

Results

Mean size-change scores for movement trials were then calculated for each subject and, together with data from the static control trials, entered into a 2 × 2 × 2 repeated-measures analysis of variance (ANOVA) which consisted of the following factors: the final position of the limb (near vs. far); the type of trial (movement trial vs. static (control) trial); the type of lenses worn (clear vs. prism).

The ANOVA revealed a statistically significant main effect of final limb position (means: near position = −0.7 [1.1] vs. far position = 0.4 [1.0]; $F[1\ 13] = 67.7$, $P < 0.0001$) and a significant limb position × trial type interaction effect $F[1\ 13] = 70.8$, $P < 0.0001$). All other main and interaction effects failed to reach statistical significance. Specifically, there was no significant effect of the type of lens worn by subjects ($F[1,13] < 1$, $P = 0.9$) and the type of lens worn did not interact reliably with any other factor (Fig. 2).

Relevant means for the limb position × trial type interaction are presented in Fig. 3. This effect was investigated by examining the simple main effects using linear contrasts between means. These analyses revealed that there was a significant effect of the type of trial completed by subjects (i.e., movement trials vs. static [control] trials) at both near and far limb positions (minimum $F[1,13] = 28.5$, $P < 0.0001$). More importantly, the analyses revealed that there was a significant of effect of limb position for movement trials (means: far = 1.1 [0.86] vs. near = −1.5 [0.73]; $F[1,13] = 104.5$, $P < 0.0001$; Fig. 3). Participants, when moving to the far location ("away" trials) estimated that the afterimage increased in size, but, when moving

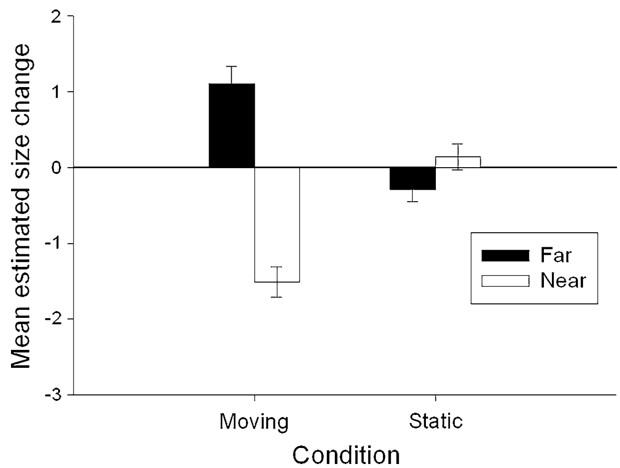

Fig. 3 Mean size change ratings as a function of condition and ending position. Note how in the moving conditions only the Taylor illusion was elicited in the appropriate directions

to the near location ("toward" trials) judged their afterimage to decrease in size. This effect was not apparent, however, for static position trials in which the subject's limb was placed at the near or far location (means: far = −0.29 [0.60] vs. near = 0.14 [0.65]; $F[1,13] = 2.8$, $P > 1$).

Finally, examination of the mean ratings of initial afterimage size showed substantial differences in initial afterimage rating dependent upon the position of target object: on trials in which the afterimage was obtained at the near dowel, the mean initial rating was 1.88; when obtained from the more distant starting point, afterimages mean initial rating was 4.96; this effect occurred regardless of the goggles worn or the presence or otherwise of a movement following the obtaining of the initial afterimage. In other words, although the experimental cards were designed to subtend the same visual angle as item 4 (the midpoint) in our scale, participants did perceive size difference between these cards, even in the absence of scene cues regarding target distance. The relevance of this fact for future experiments on the Taylor illusion is discussed below.

Discussion

First, the fact that the Taylor illusion was reported so infrequently in the static control trials (see Fig. 3) suggests that the effects reported in the main experimental trials here and elsewhere (Bross 2000; Carey and Allan 1996; Mon Williams et al. 1997) can indeed be viewed as genuine reports of perceived size changes, rather than as participants misinterpretations of image deterioration. This control was not included in Carey and Allan (1996) or in the other reports of the illusion and related phenomena (Gregory et al. 1959; Mon-Williams et al. 1997; Taylor 1941).

It was expected that under the "normal lens" conditions, the usual pattern of perceived size changes would be reported, while under the "prism lens" condition no size changes would be perceived at all. This hypothesis was based upon the assumption that the failure of participants to report perceived size changes under Carey and Allan's (1996) non-dominant hand condition was caused by the mismatch between the visual position of the afterimage and the felt position of the hand that was subsequently moved. As is clearly illustrated (see Fig. 2) this hypothesis was incorrect: despite the fact that the visual information presented to participants did not match the proprioceptive information related to the target object's position, participants still perceived size changes in the afterimages they obtained. If anything, the size changes reported under the "prism lens" condition were of a slightly (although not significantly) greater magnitude than those reported under "normal lens" conditions.

Of course, the nature of the disparity between visual and proprioceptive information examined by Carey and Allan's (1996) non-dominant hand condition differs from that addressed by the "prism" condition reported here in at least two ways. Under the "prism" condition, the disparity occurred on the picture plane (along the X-axis, or left to right), while under Carey and Allan's (1996) non-dominant hand condition, the disparity occurred in the depth plane (i.e., the Z-axis). Perhaps disparity in depth causes a failure in participants to perceive the Taylor illusion. Mon Williams et al. (1997) note that vergence changes due to limb movements made in Taylor conditions may depend on the flash-illuminated limb being the one that is moved. Of course, how the central nervous system established such identity remains a mystery, since the current results suggest that the "proprioceptive" hand (or hand-held card) does not have to be in spatiotopic register with the "visual" hand.

In the Carey and Allan (1996) non-dominant hand condition, participants were fully aware that the hand that moved was occluded by the other hand, and that the afterimage was of the non-moving static hand. Given the cognitive impenetrability of the illusion, we doubted that knowledge about the condition would make any real difference. Nevertheless, our participants in the present study were unable to identify whether or not they were wearing prism or control glasses on any given trial (in fact we went to some lengths to ensure that this was the case). It may be that the failure to null the illusion was, in some way, the result of this unawareness. (This idea is rather reciprocal to the usual logic of prism adaptation; negative after-effects are measured after the adaptation phase to rule out the possibility that conscious awareness of visual-proprioceptive mismatch produces a strategy on the part of the participants rather than a subconscious recalibration of visuomotor maps.)

Additional experiments could rule out some of the possibilities relating to modulating effects of awareness of visual-proprioceptive mismatch. For example, providing knowledge of the prism glasses might null the illusion. Repeating the Carey and Allan (1996) non-dominant hand condition with the rapid removal of the occluding hand might reveal some binding of the afterimage to the subsequently moved hand (see also our suggestion regarding right angled prisms below; also see Davies 1973).

Taylor (1941) suggested that the illusion is mediated by appropriate vergence eye movements to the moving limb. Mon-Williams et al. (1997) have reconfirmed Taylor's observations that eliminating vergence movements with a fixation point eliminates the illusion. Mon Williams et al. (1997) controlled vergence movements by using a small red LED to eliminate them. In the first condition the LED was placed coincident with the centre of the card, and remained stationary while the subjects moved the card away after an afterimage was obtained. In their second condition, the LED was placed on the card whilst the experimenter moved the card away from the participant. Their second condition elegantly demonstrates that vergence is sufficient for the illusion, since illusion effects were obtained and no other distance cues should have specified change in target distance (although some monocular cues such as height in the visual field may well have been present if the LED was not at eye level and centred on the participant's midline). In their first condition, vergence was kept unchanging and illusion effects were not obtained. The authors concluded from this finding that vergence changes are necessary for the illusion's occurrence.

Of course, vergence provides an extremely powerful distance cue, so it is conceivable that a vergence signal about *unchanging* target depth may override any proprioceptive or efference copy signals about *changing* target depth. In many models of distance estimation, depth cues are weighted in some fashion; in such models visual and oculomotor cues would likely receive heavier "weightings" than cues from the motor system about arm position. For Mon-Williams et al. (1997) to convince us that vergence is the key, a different form of evidence is called for: the measurement of eye movements spontaneously in Taylor conditions and demonstration that the presence or absence of the illusion depends upon the magnitude and direction of vergence change. Illusions are not always obtained on each trial in every subject, and if the vergence explanation of the Taylor illusion is correct, than variance in the occurrence of proprioceptively-driven vergence should account for occasional "no change" trials or the rather rarer "no change" subjects. Mon-Williams et al. (1997) came close to such an experiment using an afterimage of the hand "viewed whilst participants exercised voluntary vergence" (pp. 501–502), but difficulties in voluntary vergence production and intrusive conjugate eye movements may limit the usefulness of that data. Additionally, the gain of vergence over such distances is small (Mon-Williams and Tresillian, personal communication) and would require remarkably accurate tracking for its evaluation in Taylor illusion conditions.

In any case, if the vergence explanation of the Taylor illusion is correct, then vergence changes in our participants must have been essentially normal, in spite of the large mismatch between felt card position and seen card position produced by the prism goggles. (Bross found Taylor illusions were obtained when participants closed their eyes in darkness after the afterimage was obtained. If gaze moved towards primary position, vergence signals may have been disrupted; Bross 2000.) This fascinating possibility deserves future study.

A further way in which Carey and Allan's (1996) non-dominant hand condition differs from the "prism" condition is of a more fundamental nature: under the former condition, an afterimage was obtained of one hand, while the movement was carried out by the other; under the latter, the movement was carried out by the same hand as was used for holding the target object when the afterimage was obtained. It may be that the failure to perceive the Taylor illusion under such conditions might rest with the incompatibility between the shape of the afterimage and the shape (perhaps specified proprioceptively) of the object being moved (or some top down influence related to knowledge of right and left hand, etc.). This possibility could be examined through the use of right-angled lenses (Kohler 1962) which produce a mirror-image of the presented stimulus: if the shape of the target is indeed a significant factor, the presentation of a reversed afterimage of the might allow the mapping of the afterimage to the distant hand that is subsequently moved. Consequently the participant would reliably perceive the Taylor illusion. In the present study, such shape confounds were absent by design, and the illusion was obtained in mismatch conditions, unlike in Carey and Allen (1996).

It was surprising to find that size-distance scaling still operated in such a visually impoverished environment: many experiments suggest that size constancy tends to break down in darkness when cues to distance are largely eliminated and participants begin to make size judgements based on retinal, and not real, size (although many of these experiments used target distances well beyond peripersonal space; see Boring 1942 for review). In spite of such conditions in our study, participants produced appropriately larger initial ratings for the far card and smaller ratings for the near card. That is, they showed size constancy in total darkness (manipulations of vergence and/or hand/arm proprioception a might reveal the source of the distance information in darkness which allows for the mechanism to remain functional). The experimental card sizes and the size of point 4 in the rating scale provided identical retinal image sizes, given the three different viewing distances for towards and away trials (and the midpoint between them for the rating scale training). Future studies could utilise targets (and the midpoint of the training sequence) which are identical in physical size, or could be "titrated" to individual participants as follows: manipulate real size until participants make identical size judgements in static trials at the near and far dowel and at the midpoint in between. A different approach to this problem is to carry out a training session in the dark, using afterimages as illustrations of each point on the scale. However, such a procedure would take a great deal of time to implement and could tire participants before the actual experiment commenced. A compromise that might be used is to train and test participants in normal light and then to repeat the size judgements in darkness with participants rating each scale point as an afterimage.

The results of such trials would make it quite clear whether or not training in daylight is adequate for the rating of afterimages and, on the basis of these results, research methods can be adapted accordingly.

The rating scale itself does not allow unambiguous comparisons of towards and away movement illusion magnitude. The edge length of scale points did not increase smoothly: between points 1 and 4, each edge length increase was of approximately 1.4 cm; between points 4 and 7, each edge length increase was of approximately 2.8 cm. This produced a substantial contrast around the midpoint of the scale: the edge length change between points 3 and 4 is half that between points 4 and 5; it might be argued on the basis of this difference that participants were discouraged from reporting perceived size increases. This is a possible explanation of the results that showed a greater tendency to report perceived size decreases in the present study, while the opposite pattern was reported by Carey and Allan (1996).

A possible solution to this problem is the use of steadily increasing edge length increases. In the case of a seven point scale, as was used in this study, 126% edge length increases (i.e. the edge length of point 2 is 1.26 times the edge length of point 1) would allow the retention of all pertinent aspects of the scale used in this study: point 1's edge length would be half that of the midpoint 4, which is, in turn, half the edge length of point 7. The use of such a scale could go some way to investigating anisotropies in illusion magnitude for towards versus away movements.

Conclusion

The results of this experiment suggest that the failure of Carey and Allan's (1996) non-dominant hand condition to produce the Taylor illusion cannot be explained by disparity between visual and proprioceptive information (in the picture plane, at least). It is likely that another factor, possibly related to the fact that different hands were used for the obtaining of the afterimage and the actual movement carried out, is at the root of the "non-effect" reported in the original study.

It is clear that the production of a disparity between seen and felt position is not sufficient to prevent the perception of the Taylor illusion. An alternative explanation is that information regarding distance rather than position in the coronal plane may be central to the decision whether the moved object is the object from which the afterimage was obtained. Other visual-proprioceptive illusions are similarly tolerant of displacements in the coronal plane (e.g. Botvinick and Cohen 1998). Nevertheless, other visual-proprioceptive illusions (and multi-sensory responsive neurons in the Macaque monkey) can also be spatially intolerant to differences in seen and felt stimuli in depth (e.g. Graziano 1999; Rorden et al. 1999). In many experimental paradigms, vision can dominate non-visual kinaesthetic and proprioceptive information, such as in demonstrations of "visual capture of touch" (e.g. Pavani et al. 2000). Nevertheless, the limits of such capture for different tasks in different experimental paradigms remain to be determined. The Taylor illusion may serve as a useful tool for just such a purpose.

Much work remains to be done in perfecting a size perception rating procedure for experiments examining the Taylor illusion: training, testing and rating systems all remain, to greater or lesser extents, flawed and in need of some revision. Certain procedures, outlined previously, may improve this state of affairs.

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