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RESEARCH ARTICLE

Eye position affects the perceived location of touch

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Abstract Here, we demonstrate a systematic shift in the perceived location of a tactile stimulus on the arm toward where the eye is looking. Participants reported the perceived position of touches presented between the elbow and the wrist while maintaining eye positions at various eccentricities. The perceived location of the touch was shifted by between 1 and 5 cm (1.9°–9.5° visual angle) by a change in eye position of ±25° from straight ahead. In a control condition, we repeat the protocol with the eyes fixating straight ahead. Changes in attention accounted for only 17% of the shift due to eye position. The pattern of tactile shifts due to eye position was comparable whether or not the arm was visible. However, touches at locations along the forearm were perceived as being farther apart when the arm was visible compared to when it was covered. These results are discussed in terms of the coding of tactile space, which seems to require integration of tactile, visual and eye position information.

Keywords Touch · Gaze · Fixation · Spatial display · Localization · Shift · Direction · Mislocalization

Introduction

The perceived position of an object in space is surprisingly subjective. There is no single sense designated for spatial perception and object localization. Instead, the visual, auditory and tactile senses can each contribute to the localization of objects and events. The senses provide spatial location information, which is often redundant, but each sense uses a different reference frame to represent location: vision indicates the position of objects relative to the retina (i.e. relative to other objects in view), auditory signals code the position of sounds relative to the head, and tactile signals indicate location on the body's surface. Yet, we have a single unified perception of the world in which the inputs from the different senses are combined. Combining the inputs from the different senses requires knowledge of the relative position of these reference frames.

If the eye, head and body are not aligned, systematic errors in localization are found, and perceptual space cannot be objectively defined. When the head is not aligned with the body the perceived location of a visual stimulus (Rossetti et al. 1994; Wexler 2003), an auditory stimulus (Lewald and Ehrenstein 1998), and a tactile stimulus (Ho and Spence 2007) are shifted. Similarly, when the eyes are not straight ahead (relative to the head), the perceived location of a visual stimulus (Harris and Smith 2008; Kopinska and Harris 2003; Lewald 1998) and an auditory stimulus (Graziano 2001; Lewald and Ehrenstein 1996a, b; Weerts and Thurlow 1971) also shift. Ho and Spence (2007) recently found errors in localizing a touch on the torso in the opposite direction to head displacement, presumably related to combining head and tactile references frames. The effect of eye position on tactile localization is currently unknown.

One theory of how multisensory integration of spatial perception is achieved involves mapping all the modalities into a single frame of reference (Pouget et al. 2002). Since visual and auditory localization errors have been shown to be predictable from eye position, this suggests the visual reference frame as a potential candidate for a common

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frame. Converting tactile information into a retinal frame requires knowledge of eye position. Proprioceptive signals of eye position are available in the monkey somatosensory cortex (Wang et al. 2007) and could be involved in converting tactile information into a retinal reference frame. We, therefore, tested for errors in tactile localization related to eye position.

Methods

Participants

Experiment 1 had ten participants (four females) with a median age of 25 years. Experiment 2 had a subset of eight participants from the first experiment (three females) with a median age of 25 years. Experiment 3 had nine participants (four male) with a median age of 26 years (three of which participated in the previous experiments). Each participant completed informed consent agreements, which conformed to the ethical guidelines of York University and the Treaty of Helsinki.

Apparatus

Touch stimulators (tactors) were made from small solenoids mounted on a plate with the pins facing upwards. When the solenoid was powered, the pin was pushed out about 2 mm. Solenoids were controlled by amplified 5-V signals from a CED1401 controlled by a PC. All touches were 50 ms in duration. Participants placed their arm in front of their torso on a horizontal plane with their elbow bent at ∼90° on the plate containing the four solenoids arranged at 7.6, 12.6, 17.8 and 23.2 cm relative to a ruler placed on the far side of the box (see Fig. 1). The solenoids were spaced so that participants could not infer the position of any one stimulator from the position of the other stimulators. A piece of paper initially covered the tactors so that their location could not be seen by the participant. The paper was removed only when the participant's arm obscured the tactors from view. Participants wore ear mufflers because of the sound generated from the solenoids.

Four green LEDs were arranged 10 cm further away from the participant's torso under the plastic ruler at −13.3°, −2.7°, 9.0°, 19.5° relative to straight ahead (negative indicates left). The luminance of the LEDs was measured at 11.8 cd/m^2 and the background luminance in the room was measured as 0.16 fcd.

Procedure

Participants placed their chins in a chinrest and their arm over the tactors as shown in Fig. 1. To start the experiment, participants fixated[1] one of the four lights and maintained fixation after the light was turned off (after 1–1.5 s). After a variable delay, (100–450 ms) one of the four tactors was activated. The ruler was illuminated 100 ms after the tactor was turned off, and participants were allowed to move their eyes. They verbally reported where along the scale they perceived the touch to have occurred (in millimeters). While the experimenter entered the response, participants moved their eyes to the next fixation position. Each combination of eye position and tactor was presented ten times for a total of 160 trials, taking about 20 min to complete.

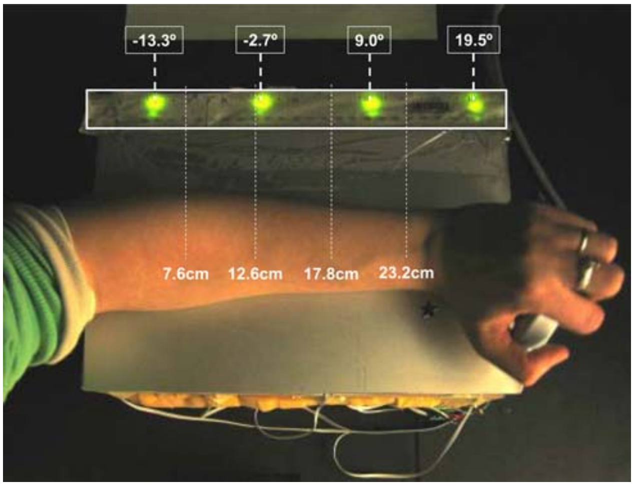

Fig. 1 Touch plate, ruler and fixation lights. The plate on which participants placed their arm (*left* or *right*) is shown. The four solenoids protruded through holes in the plate under the arm (as indicated by the *dashed lines*). The four fixation lights were placed under the ruler (redrawn in *white*). Participants aligned the creases on their wrist with a reference *star* on the *box*. Exact alignment was not important since tactors and lights were fixed relative to the ruler. All distances reported were also relative to the ruler

In experiment 1, each participant completed the experiment twice, once with their left arm and once with their right arm, in a counterbalanced design.

In experiment 2, the procedure was the same but the setup was slightly different; the arm being stimulated was not visible. A cut-out shoe box was placed over the forearm and a black cloth was draped over the box covering the participant's entire left arm—from their shoulder to past their fingertips. The ruler was moved onto the top-far side of the shoe box in order for it to be visible to the participant. The ruler was still 10 cm away from the participant's torso but was now elevated by 32.9° from its original position. The position of the LEDs behind the ruler now corresponded to −19.6°, −4.9°, 11.5°, 25.7° relative to straight ahead (negative indicates left).

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[1] Eye position was not measured since timing and accuracy of the eye's position were not critical to the experiment.

In experiment 3, the ruler and LEDS were kept in the "high position" as in experiment 2 (see degrees above). A fixation light was placed at an additional elevation of 12.8° (another 6 cm) above the ruler and the LEDs. In this experiment, participants fixated the light while the other LEDs and the touches flashed on and off (delays between them being the same as reported above). As before, participants were allowed to move their eyes only after the touch in order to indicate the perceived position of the touch using the scale. Each participant completed this "fixed-eye-position-control" twice with the left arm being stimulated, once with the arm visible and once with the arm covered, in a counterbalanced design.

Results

Experiment 1: effect of eye position

The perceived location of each touch was converted into arm coordinates taking into account that solenoid 1 (and fixation 1) was on the elbow on the left arm but on the wrist on the right arm. After the conversion, larger responses always indicated that the touch was perceived as closer to the wrist while smaller responses indicated that the touch was perceived as closer to the elbow (regardless of the arm tested). There was no significant difference between data collected using the left and right arm ($F_{1,9} < 1$, n.s.). The data from both arms were, therefore, pooled for Fig. 2 and Table 1. The effect of trial number was assessed to see if participants had more variable responses at the beginning of testing. There was no effect of trial number on the responses ($F_{1,9} < 1$, n.s.).

Figure 2 shows the significant linear effect of eye position on the perceived location of each of the four touches on the forearm (linear contrast analysis: $F_{1,9} = 19.13$, $P = .002$, $\eta^2_{\mathrm{P}} = .680$). The perceived location of each touch was shifted in the same direction as the eye position; that is, when participants looked left, they perceived the touch as being more toward the left than when they looked to the right.

Interestingly, the effect of eye position was not the same for all locations on the arm: there was a significant touch-location-by-fixation interaction [$F_{9,81} = 5.85$, $P = .003$ (Greenhouse–Geisser corrected), $\eta^2_{\mathrm{P}} = .394$]; the slopes for each touch site are slightly different (as shown in Fig. 2).

Location of touch biased toward the elbow

The average perceived location of the tactor was compared to the true position of each touch for each fixation with a one sampled t test. When participants fixated the first, second, and third fixation positions, responses were significantly shifted toward the elbow ($t_{31} = -5.50$, $P < .001$; $t_{31} = -4.36$, $P < .001$; $t_{31} = -2.59$, $P = .015$, respectively). However, when participants fixated the fourth fixation position (nearest the hand), the perceived position was not significantly different from the veridical position ($t_{31} = -1.031$, $P = .31$).

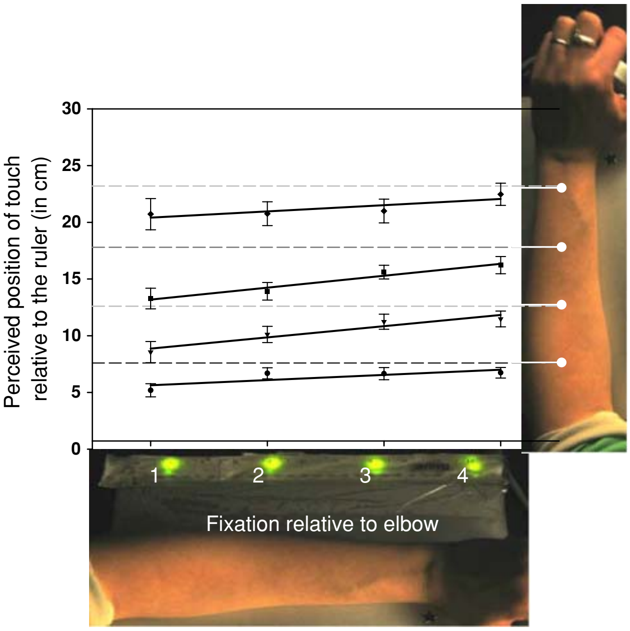

Fig. 2 The perceived position of touch plotted as a function of fixation. The horizontal axis corresponds to the locations of the four fixation lights, where 1 is the light nearest the elbow. The vertical axis is the perceived location of the touch where 0 is closest to the elbow. The *dashed lines* indicate the actual locations of the touches—connected to *dots* symbolically showing the positions of the touches on the arm. Data for each of the tactors are shown using different symbols. Data are averages of both left and right arms with the standard error between participants shown. Since the statistical analysis revealed a significant linear interaction effect between fixation and the touch locations, best fit linear regressions have been plotted to the averaged data for each touch location

Experiment 2: the effect of covering the arm

The first experiment suggested that the perceived location of a touch depends on eye position. However, the shift in the perceived touch might instead be due to seeing different pieces of skin—the perceived touch being shifted toward the piece of skin that was in view. To test this, we repeated the experiment with the same participants, but this time we covered the arm (see "Methods" above).

The perceived position of touches were analyzed with a three-way repeated-measures ANOVA: vision of arm (2 yes/no) × touch location (4) × fixation (4). There was no main effect of vision ($F_{1,7} < 1$, n.s.). There was still a significant linear effect of eye position on the perceived location of the tactor (same linear contrast analysis as

Table 1 Table showing the means

	Real position	Fixation 1	Fixation 2	Fixation 3	Fixation 4
Experiment 1					
Elbow touch	7.6	5.2 (0.4)	6.7 (0.2)	6.6 (0.3)	6.7 (0.3)
Second from elbow	12.4	8.6 (0.6)	10.1 (0.4)	11.2 (0.4)	11.5 (0.2)
Second from wrist	17.8	13.3 (0.6)	13.9 (0.5)	15.6 (0.3)	16.2 (0.3)
Wrist touch	23.2	20.7 (1.2)	20.8 (1.0)	21.0 (0.9)	22.5 (0.8)
Experiment 2					
Elbow touch	7.6	5.9 (0.4)	7.6 (0.5)	8.4 (0.5)	8.2 (0.7)
Second from elbow	12.4	10.2 (0.9)	11.9 (0.8)	13.3 (1.0)	13.6 (1.1)
Second from wrist	17.8	13.6 (1.2)	14.7 (1.0)	16.5 (0.9)	17.3 (1.4)
Wrist touch	23.2	18.9 (2.7)	20.9 (1.5)	21.7 (1.2)	22.9 (1.3)
	Real position	Distracter 1	Distracter 2	Distracter 3	Distracter 4
Experiment 3					
Elbow touch	7.6	6.0 (0.6)	6.5 (0.6)	6.1 (0.5)	6.0 (0.6)
Second from elbow	12.4	9.7 (0.6)	11.0 (0.6)	10.8 (0.6)	10.7 (0.6)
Second from wrist	17.8	15.5 (0.6)	15.3 (0.6)	16.3 (0.6)	16.3 (0.6)
Wrist touch	23.2	21.4 (0.9)	21.2 (0.9)	21.5 (0.8)	21.7 (0.9)

The mean (± SE) perceived positions (cm) relative to the ruler for each of the four locations of touches, for each of the four fixations. The actual positions are also indicated. To interpret these scales, see Fig. 1. Experiment 1 is when the arm was visible (data averaged for left and right arm since they were not significantly different). Experiment 2 is when the arm was covered and the skin was not visible (left arm only). Experiment 3 is when fixation was held constant and distracter lights were presented in the same positions as in experiment 1 and 2 (left arm only; data averaged for arm visible and arm covered since vision did not interact with the above presented distracter × touch position effect)

reported in the first experiment: $F_{1,7} = 20.07$, $P = .003$, $\eta_{\mathrm{P}}^2 = .741$; means are presented in Table 1). More importantly, there was no effect of vision on the location-by-fixation interaction (there was no three-way interaction of vision × location × fixation; $F_{9,63} < 1$, n.s.). This can be seen in Fig. 3a as the slopes are the same whether the arm was visible (solid) or covered (dotted).[2]

Arm appeared shorter when covered

While the effect of fixation was not altered by the visibility of the skin, Fig. 3b reveals the surprising observation that the locations of the touches were perceived as closer to each other when the arm was covered. This effect is not affected by fixation, it appeared as a significant interaction between vision and touch location ($F_{1,7} = 104.5$, $P = .002$, $\eta_{\mathrm{P}}^2 = .759$).

Figure 3b plots the average perceived position of each touch as a function of the actual touch position. The line representing the perceived locations of the touches when the arm was covered (dashed) has a shallower slope than line representing the data with vision of the arm (solid). The perceived distance between the two farthest touches was 16.9 cm when the arm was visible compared to 13.6 cm when the arm was covered. Indeed, a few of the participants reported being shocked when the box and cloth covering their arm were removed—they felt that their arm was shorter than it really was, and it appeared to grow the instant the cover was removed!

Experiment 3: fixed-eye-position-control

Since touches have been reported to move with attention (Kilgard and Merzenich 1995; Flach and Haggard 2006), we wanted to disassociate eye position and attention. In

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[2] Upon the request of a reviewer, we tested the hypothesis that the effects reported here were due to a ventriloquism effect between the flashed LED and the touch. As there was a variable delay between the LED offset and tactile onset (100–450 ms), a separate analysis of trials with a short delay (100–275) was compared with long delays (276–450) for both experiment 1 and 2. If the effect reported was due to spatial ventriloquism, then shorter delays should yield stronger effects (larger shifts in position) while longer delays should yield smaller or no effects at all. The average perceived location of the touches (4) at each fixation (4) in each experiment (2) was calculated separately for short and long delays by pooling the participant's data. Regressions were fitted to each touch across the four fixations separately for the short and long delays (in the same way as is presented in Figs. 2, 3a, and 4a in the paper). If the effects were due to ventriloquism, then there should be larger slopes for shorter delays. A paired samples *t* test comparing eight short delays and eight long delays (four with vision and four without vision) revealed no significant difference between the slopes for the two delay groups $t_7 = 0.29$, $P = .78$).

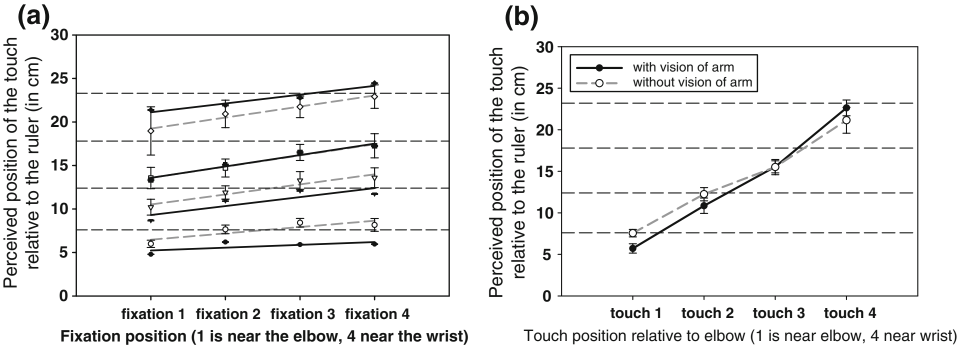

Fig. 3 Effect of vision of the arm. *Solid black lines* (*filled symbols*) are regression fits to the data points obtained when the arm was visible (*left arm*), and *dotted lines* (*open symbols*) are regression fits to the data points when the arm was not visible (*left arm*). *Error bars* correspond to between-subject standard errors. **a** Plots the perceived position of the four touches (in cm) as a function of fixation position. The slopes of the *dashed* and *solid regression lines* are not significantly different, meaning that the effect of fixation is the same regardless of if vision of the arm is available. **b** Plots the mean perceived position of the touches averaged across fixations and plotted as a function of the touch's positions on the arm. A comparison of the slopes of the two lines shows the significant interaction effect between vision and the perceived positions of the touches: the touches are perceived to be closer together when the arm is not in view

order to test for an effect of attention, we repeated experiments 1 and 2 but with fixation maintained straight ahead and thus separated from the distracting flashing LED that preceded the touch. The flashing LED was a distracter that caused attention to be diverted, at least partially, from fixation. The perceived position of touch with a fixed eye position was analyzed with a three-way repeated-measures ANOVA: vision of arm (2 yes/no) × touch location (4) × distracter position (4).

There was a small but significant linear interaction effect of the distracter light on the perceived location of the touch (linear contrast analysis: $F_{1,8} = 12.153$, $P = .008$, $\eta^2_{\mathrm{P}} = .603$; see Table 1 for means). This significant effect suggests that at least some of eye position effect reported in experiments 1 and 2 may be due to the redirection of attention toward fixation. However, as can be seen from Fig. 4a, the effect due to attention is much smaller than the effect reported from experiment 1 that is due to eye position.[3] Again, there was no interaction of vision on the touch-location-by-distracter interaction (there was no three-way interaction between vision × touch location × distracter LED: $F_{9,54} < 1$, n.s.).

Finally, we again found a significant linear interaction between vision and touch location ($F_{1,8} = 10.021$, $P = .013$, $\eta^2_{\mathrm{P}} = .556$, Fig. 4b). The touches were perceived as being closer to each other when the arm was covered. This confirms the observation obtained by comparing experiment 1 and 2 (Fig. 3b).

Discussion

These experiments have shown that the perceived location of a touch on the forearm depends not only on which area of the skin receives mechanical pressure but also on non-tactile information concerning the position of the eyes in the head and attention. The effect of eye position was the same whether the arm was visible or not, but a curious effect of the arm being covered was that it appeared to shrink. Only directing the eyes to the wrist allowed the tactors to be accurately localized. This suggested that the eye position-dependent system for localizing touches is calibrated for looking near the hand.

Shift with attention

The fixed eye-position experiment found that a small amount of the shift in the perceived position of a touch appears to be due to shifts in attention. Even when participants were not looking eccentrically, the perceived position of a touch was shifted in the direction of a flashed light. But the shift due to the distracter light was much smaller than the shift due to eye position (up to 2 cm vs. up to 5 cm). Since attention only accounted for a small amount of the initial shifted touch effect reported, we conclude that fixation has an effect of moving the perceived location of touches above and beyond attention. However, we concede that in the fixed eye position experiment, attention may have been divided (between the fixation and the distracter positions), which would result in

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[3] Since different participants were used in experiment 3 and experiments 1 and 2, this smaller effect could not be statistically tested with a repeated measures design. However, by taking the average slope of the regression lines when the eyes were in a fixed position (Fig. 4a solid black line) and dividing it by the average slope of the regression lines when the eyes changed fixation (Fig. 4a dotted black line), we have calculated that 17% of the effect initially reported as due to eye position, was actually due to the effects of attention.

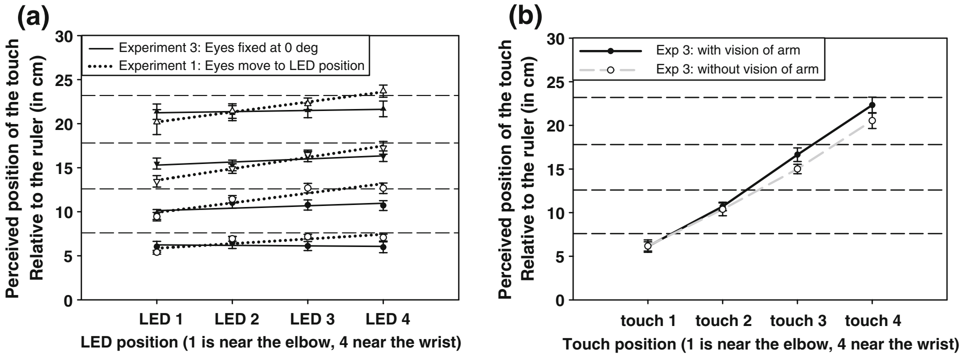

Fig. 4 Fixed eye position control experiment. Data points are from left arm only, *error bars* correspond to between-subject standard error values. **a** The different touch positions are shown with different symbols. Lines are regression fits to the data points obtained by averaging across vision conditions (arm visible and arm not visible) since there was no significant interaction of vision on the effect of the distracter lights. The perceived position of the four touches (in cm) is plotted as a function of the LED position. *White symbols* (and *black dotted lines*) are for data when the eye moved to the position of the LED. *Black filled symbols* (and *black solid lines*) are for data when the eyes did not move to the LED position—they were fixed at a constant position throughout. The slopes for each touch position are much smaller when the fixation is not moved to the distracter LED, suggesting that the effect of attention only explains part (~17%) of the effect of eye position on the perceived position of the touch. **b** Plots the mean perceived position of the touch from experiment 3 averaged across fixations and plotted as a function of the touch's position on the arm. As in Fig. 3b, the difference in *slope* indicates that the touches are perceived to be closer together when the arm is not in view

a smaller shifted touch effect even if the entire effect were due to attention (see also Rorden et al. 2002 for a discussion of attention and eye position affecting tactile variance). However, given that the effect nearly disappears when gaze is constant, we suggest that there is more to the shifted touch effect than attention alone.[4]

These shifts of touch in the direction of vision might be an indication of a tactile ventriloquism (see footnote 3; also, there have yet to be any reports of visual-tactile spatial ventriloquism). However, there have been reports of attention significantly affecting the perceived location of a touch in the rubber hand illusions and in the cutaneous rabbit effect (CRE). Research on the rubber hand illusion has shown that proprioception and touch are very susceptible to localization errors since participants perceived touches on the rubber arm to be on their own skin (see Austen et al. 2004 for some surprising effects of the rubber hand; see Makin et al. 2008, for a review).

Kilgard and Merzenich (1995) showed that in the CRE while the presentation timing affects the amount by which the touches move, the location that the touch moves to is "dramatically shifted toward an attended region" (p. 663). Flach and Haggard (2006) report the same effect of attention but also tested for an effect of eye-gaze on the perceived location of the touch. They found that the direction in which the touches moved in the CRE was not affected by eye-gaze, instead eye-gaze only modulated the amount by which the touches moved. Flach and Haggard similarly conclude that the CRE has an effect of moving tactile perception above and beyond the effect of attention. Thus, while attention may modulate the CRE, it is not the prime originator of the effect. Likewise for the phenomenon of the perceived location of touch shifting with eye position, attention appears to only provide a modulation of an already present effect.

Shift with eye position

The effect of eye position on the perceived location of touch reported here for the first time, is similar to the effect of eye position on the perceived location of visual (Harris and Smith 2008) and auditory (Weerts and Thurlow 1971) stimuli. However, auditory errors have also been reported in the opposite direction to eye position (Lewald and Ehrenstein 1996b) and gaze (Lewald and Ehrenstein 1996a).

Lewald and Ehrenstein (1998), showed that the perceived location of a visual stimulus shifts in the same direction as eye position but in the opposite direction from head position. They thus speculated that the two effects may cancel each other out. A similar situation may occur for the perceived location of touch since it also shifts in the same direction as the eyes (as reported above) but in the opposite direction from head position (Ho and Spence 2007).

The existence of eye position-dependent errors suggests that touch might be coded in a visual reference frame and that the observed shifts may reflect imperfections in the conversion process. The error in the conversion process might arise from inaccurate eye position knowledge (Harris

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[4] Similarly, one might argue that the shifted touch might have been due to a response bias. However, the same logic applies since a response bias in this experiment would probably be towards the flashed LED, and should then have appeared in the results of experiment 3. Since the shifted touch effect is minimal in experiment 3, we feel that if a response bias were present it would be relatively minimal in comparison to the size of the effect due to eye position.

and Smith 2008). These results seem at odds with Avillac et al. (2005), who found that tactile responses to a touch on the face of macaques were unaffected by eye position. However, we found that even different parts of the arm were affected differently by eye position and differently for each participant. It is thus unlikely that all parts of the body would be affected equally or similarly across species. The fact that one can see some body parts more easily than others may play a role in determining the reliability or mobility of tactile perception.

Bias towards the elbow

Most of the eye positions used in this study were associated with a bias in the perceived location of the touch towards the elbow. This is reminiscent of a children's game where, without looking, you have to determine when someone has reached the crease inside your elbow. Inevitably you think you are being touched in the elbow crease before you actually are. This elbow bias has been previously reported for a touch on the forearm (Cholewiak and Collins 2003; Stolle et al. 2004; though see Boring 1942). We consider this apparent elbow bias to be an artifact associated with the eye positions used in this experiment. In the normal configuration of the arms, fixation is usually toward the wrists or hands and tactile localization (on the forearm) is correct. As such, it is practical that the tactile system has evolved such that a touch is accurately localized when looking at the hands.

Arm appears shorter when covered

There were two potential confounds for the "shortening arm" effect reported in experiment 2. Firstly, there may have been a practice effect (since experiment 2 was performed 6 months after experiment 1). In experiment 3, we replicated the arm shortening effect even though the order of the conditions (arm visible vs. arm not visible) was counterbalanced. Secondly, the ruler (and LEDs) was at a different elevation for experiments 1 and 2. In experiment 3, we replicated the arm shortening effect with the ruler in the same position for both the "arm visible" and the "arm covered" conditions. Therefore, the perceived shortened arm effect cannot be explained by practice effects or changes in the visual angle of the scale used for responding. Instead, the effect seems to be a direct consequence of the arm not being visible.

Since touches on the arm appeared substantially closer to each other when the arm was not in view, it seems that vision of the skin spreads out the locations of the perceived touches. We have no explanation for this novel finding but it may be to do with the perceived distance of the arm from the body. The hypothesis that touch might be coded in a visual reference frame would also suggest that touch may be coded in terms of visual angle. But, conversion from linear displacement on the skin to angular coordinates requires distance information. Thus, if touch is coded in angular coordinates, then the data we have presented, which shows that touches appear closer together when the arm is not in view, might correspond to the arm being perceived of as physically closer to the eyes when it was not in view. If the arm does indeed appear shorter when it is not visible, then the size of "near space" might also appear smaller in the dark (Longo and Lourenco 2007). The hypothesis that near space might be smaller without vision (or with obscured arms) is a stimulating area for future research.

Conclusion

This study has shown an effect of eye position on tactile localization that seems to indicate a coding of tactile information in a visual reference frame. Transforming a touch into a visual frame of reference might be necessary for a unified percept of the world, since auditory stimuli also appear to be coded in this common visual frame. The dependence of perceived tactile localization on eye position needs to be taken into account when designing systems that depend on tactile localization, e.g., the development of tactile directional navigation and warning signals for drivers (de Vries et al. 2008; Ho et al. 2006; Segond et al. 2005), and sensory substitution systems (Danilov and Tyler 2005). For these systems to function optimally, they need to incorporate eye-related as well as the head-related transform functions as suggested by Ho and Spence (2007). Determining where something is on the skin is not simply a case of detecting the piece of skin that was activated.

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