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RESEARCH ARTICLE

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What the hand can't tell the eye: illusion of space constancy during accurate pointing

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Abstract When we press an elevator button or pick up a coffee cup, different visual information is used to guide our reach and to form our conscious experience of these objects. But can the information guiding our hand be brought into awareness? The fact that we can see and feel our own hand in action suggests that it might be possible. However, the dual visual systems theory claims that on-line control of movement is governed by the dorsal stream of visual processing, which is largely unconscious. Two experiments are presented as strong tests of the hypothesis that the visual information guiding on-line pointing in healthy human adults is inaccessible for conscious report. Results show that participants are incapable of consciously accessing the information used in pointing, even though they can see and feel their hands in action and accurate performance depends on it.

Keywords Vision · Action · Space constancy · Visual systems

Introduction

The perception of a stable world despite eye movements is often attributed to mechanisms of *compensation* (i.e., extraocular signals correct for image motion that occurs during the saccade) (Bridgeman and Stark 1991; von Helmholtz 1962; Sperry 1950; von Holst and Mittelstaedt 1954) and *saccadic suppression* (i.e. a brief period of reduced sensitivity to motion during a saccade) (Bridgeman et al. 1975, 1979). We now know that it is also assisted by the built-in assumption of a generally stable world (Deubel 2002; Deubel et al. 1996). This assumption contributes to the profound failures to detect large changes made to a scene when those changes are made during brief interruptions in viewing, coming either from blinks, eye movements, mud splats, or shifts in viewpoint (O'Regan et al. 1999; Rensink 2002; Simons 2000).

Perception of a stable world depends on correspondence being maintained between views of the same scene. For example, if the target object of the saccade is displaced a large distance while the eye is in motion, its displacement is readily detected (Bridgeman et al. 1975; Fecteau et al. 2001). Also, if the target object is extinguished briefly (*blanked*) during the saccade and then redisplayed after the saccade is complete, even small image displacements can be detected (Deubel and Schneider 1994; Deubel et al. 1996). These findings suggest that objects that are continuously present during a saccade are generally assumed to be stationary. This applies not only to the targets of a saccade, but also to other objects that serve as spatial referents for the saccade target (Currie et al. 2000; Deubel et al. 2002; Deubel et al. 1998). Continuous visibility implies spatial stability with a spatial tolerance of about 50% of saccade distance (Deubel et al. 1998).

In the present study, we asked whether these rules still apply if participants were actively engaged in manual pointing. From one perspective, manual pointing has the potential to reveal to participants that a target was actually displaced during the arm motion. This is because, unlike our profound insensitivity to our own eye movements, we are fully conscious that we are making manual movements. We are able to see these movements and even to monitor their proprioception. Moreover, it is well established that manual pointing is automatically corrected for target displacements made during an eye movement (Fecteau et al. 2001; Pélisson et al. 1986) and some studies have reported that pointing responses are biased in the direction of perception when the hand is visible (Bridgeman et al. 1997; Pisella and Rossetti 2000). The question is whether this information can be made available for conscious report.

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Alternatively, our perception of target position might be unaltered by actively pointing to objects that are also the target of saccades. This outcome is predicted by the dual visual systems theory (Goodale and Humphrey 1998; Milner and Goodale 1995), which claims that the on-line control of limb and eye movements is governed by the largely unconscious dorsal stream of visual processing. If the hand follows the eye in being immune to illusions of space constancy, it would be strong support for the dual visual systems theory.

Experiment 1: the hand is uninfluenced by space constancy

We first asked whether target blanking and jumping would influence a manual pointing task in the same way it influences conscious perception. As shown in Fig. 1, each trial began with the finger of the participant resting in the home position on a display panel. Upon the sudden appearance of two objects on the right side of the panel, the participant pointed as rapidly and accurately as possible to the target (always the lower of the two objects; the upper object was a distractor). We monitored both the eye movement and the hand movement made to the target. During the eye movement, which tended to be initiated first, one of the two objects was spatially displaced by 2 cm (a "jump") and, independently, either, both, or neither of the two objects were extinguished for 100 ms (a "blank") before being redisplayed, following the design of Deubel et al. (1998). At the end of the pointing action, participants reported which object had "jumped" during the trial. We were therefore able to associate a measure of visual awareness of target location with measures of hand position on every trial.

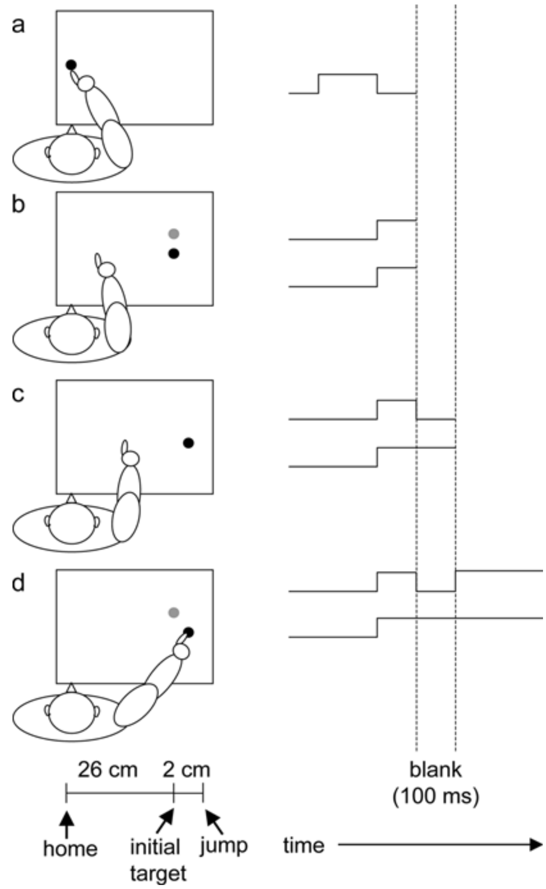

Fig. 1 Sequence of events in a typical experimental trial in which the distractor is *blanked* and the target *jumps*. Following a brief period of fixation (**a**), the target (*dark circle*) and distractor (*light circle*) objects appeared (**b**). When the participant's eye movement to the target reached its peak velocity, one or more of the objects was blanked for 100 ms and either the target or distractor jumped to a nearby location (**c**). Speed and accuracy of the pointing action to the final target location were measured (**d**). When each pointing action was completed, participants reported which of the two objects had jumped

Method

Participants

Nine right-handed university students with normal or corrected-to-normal visual acuity volunteered to participate in this study. All participants gave informed consent prior to their inclusion. The study was approved by the Behavioral Research Ethics Board of the University of British Columbia and carried out in accordance with the ethical standards set by the 1964 Declaration of Helsinki.

Stimuli

Visual displays were presented on a display panel that consisted of an array of light-emitting diodes (LED) hidden behind a translucent white Plexiglas sheet. Activation of one LED (e.g. target) was viewed by the participant as a single object. LEDs were arranged along the horizontal meridian of the panel in a 2 row x 4 column configuration (2 cm horizontal and vertical spacings). The top row consisted of four green LEDs (distractors) and the bottom row consisted of four red LEDs (targets). At the left edge of the panel, a red LED served as a fixation point. The nearest LED column was 24 cm from fixation. Participants viewed the display panel from a distance of approximately 60 cm, with head movements restricted by a chin-rest. Microswitches placed below the panel adjacent to the targets enabled the detection of the impact of the pointing movement. The experiment was performed under normal levels of ambient room illumination.

Electrooculography

Horizontal eye movements were monitored using electrooculographic (EOG) measurements. Disposable Ag–AgCl surface electrodes were placed at the outer canthi of the eyes with a ground electrode placed on the forehead. EOG signals were amplified (5–10 K) and band-pass filtered (0.1–30 Hz) using an AC preamplifier (Grass Instruments

P511), and sampled at a rate of 500 Hz. The EOG signal was passed through an analog circuit that enabled on-line triggering of stimulus events around the mid-point of the saccade.

Kinematics

Participants pointed with their right hand using a stylus. An infrared marker was placed at the tip of the stylus and 3D position was monitored using an Optotrak motion analysis system (Northern Digital) at a sampling rate of 500 Hz. Accuracy of pointing was calculated along the horizontal axis in millimeters.

Data reduction

EOG signals were low-pass filtered (2nd-order dual-pass Butterworth, cutoff 30 Hz). Saccade onset was defined as the lowest point in the EOG after which the signal increased toward the peak saccade. The end of the primary saccade was defined as the peak of the EOG signal. Raw displacement data in the primary direction of movement (horizontal axis) were also low-pass filtered (2nd-order dual-pass Butterworth, cutoff 10 Hz). Instantaneous velocity was determined by differentiating displacement using a two-point central finite difference algorithm. Acceleration was derived by differentiating velocity using the same algorithm. The first velocity equal to or greater than 30 mm s^{-1} defined the beginning of the movement. The end of the movement was defined as the time when velocity fell below 30 mm s^{-1} and the stylus contacted the display panel.

Procedure

Each trial began with the onset of the fixation point, followed 800–1200 ms later by the onset of target and distractor at either the second (26 cm) or third (28 cm) locations. Participants were instructed to point to the target as quickly and as accurately as possible. During the saccade to the target (approximately the saccade mid-point), the target or distractor jumped 2 cm backward or forward of its initial position. Simultaneous with the displacement, the target and distractor were extinguished (*blanked*) independently for 100 ms. Following each trial, participants were asked to report which of the two stimuli, the target or distractor, jumped. The combination of initial target distance (near, far), jump condition (target, distractor), jump direction (backward, forward), and blanking condition (target, distractor, both, neither) yielded 32 unique trial types. The data analysis for our questions focused primarily on trials in which only one of the two objects blanked (target or distractor). Participants performed four blocks of 160 trials over 2 days (two blocks per day) with trial order randomized within each block.

Results

Pointing movements are influenced by target jumps but not by target blanking. Participants pointed to the correct final target position, regardless of whether the target remained stationary or jumped. That is, the hand followed the eye in pointing to the final target location, regardless of target blanking or jumping. Analysis of movement times indicated that pointing took less time when the target jumped nearer toward home (412 ms) than when it jumped further away (471 ms, $F_{(1,8)}$=78.48, P<.001). However, pointing movement times to the target were completely unaffected by whether or not the distractor jumped (440 ms) (F<1).

Inspection of pointing accuracy indicated that participants adjusted their pointing in response to the displacement of the target. Figure 2A shows that participants were very accurate in pointing to the stationary target. When the target jumped toward the home position, pointing tended to undershoot the original location by 13 mm, whereas when the target jumped further away, pointing tended to overshoot the original location by 19 mm ($F_{(1,8)}$=125.48, P<.001). Object blanking had no influence on pointing accuracy (F<1). These biases in pointing accuracy indicate that participants adjusted their pointing in response to a jump toward the new target locations.

As a final check on how pointing was influenced by target jumps, we examined the kinematics of the pointing movements in detail. First, we used the velocity and acceleration profiles to determine whether modifications were made to the movement trajectories (see Chua and Elliott 1993 and Fecteau et al. 2001 for details of these procedures). These modifications typically occurred after peak movement velocity (approximately 280 ms into the 440 ms movement, on average) and were not confined to trials in which the target jumped, but also occurred when the target was stationary. The proportion of trials in which a correction was observed and the time at which a correction first occurred also did not vary significantly as a function of whether or not the target jumped. These findings are not surprising, since trajectory corrections are observed even when pointing to a stationary target (Chua and Elliott 1993; Fecteau et al. 2001).

Next, we conducted an analysis of the time after peak velocity as a proportion of movement time—an index of the time spent in the decelerative phase of the movement. Consistent with the movement time results, this analysis revealed that the length of the decelerative phase was sensitive to the target jumping (backward=.54; forward=.58), but not to the distractor jumping (backward=.56; forward=.55), $F_{(1,8)}$=32.135, P<.001. In summary, the hand was very sensitive to whether targets jumped but not to whether they blanked.

Conscious perception of object displacement is governed by blanking. Figure 2B shows that accuracy in reporting whether the target or the distractor was displaced was almost entirely determined by blanking ($F_{(3,24)}$=10.33, P<.001). When only one object was blanked, whether it was the target or the distractor, that object was reported to

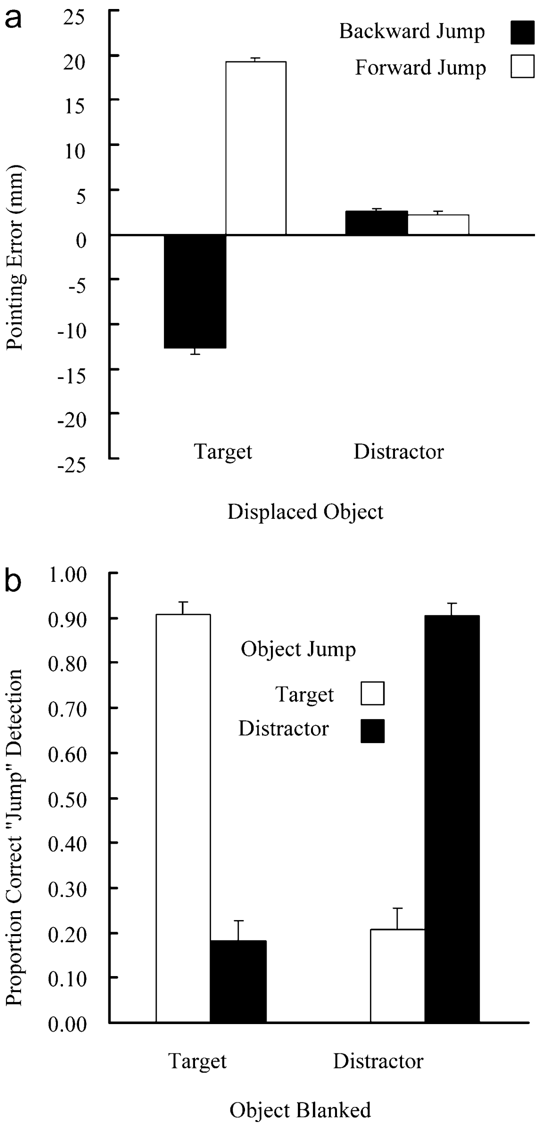

Fig. 2 Pointing accuracy in Experiment 1 relative to the original target location (**a**). Accuracy of the verbal reports in Experiment 1 regarding which of the two objects jumped during the pointing action (**b**)

have jumped ($F_{(3,24)}$=23.28, P<.001), even when it actually remained stationary.

An analysis of the trials in which both objects were blanked showed that accuracy in reporting which object jumped remained significantly above chance levels (distractor jumped=.70; target jumped=.72). The same was true when neither object was blanked (distractor jumped=.59; target jumped=.71). These results suggest that participants were not simply using the blank as a signal to report a "jump" but were relatively accurate in determining which object jumped in these situations (see also Deubel et al. 1996, 1998).

These results indicate that participants were using the continuous visibility of objects to conclude that they are stationary, even though the visual analysis that guided their pointing accurately took target displacement into account. The visible and felt hand is therefore guided by visual information to which the conscious visual system does not have access.

Experiment 2: information guiding the hand is inaccessible to awareness

To test our conclusion from Experiment 1 even more strongly, we tested a separate group of participants, whom we instructed to stop pointing as soon as they detected a jump in the target location. This design permitted us to obtain two manual responses: the initial pointing response that occurs in the absence of conscious awareness (as in Experiment 1) and a second response that occurs only following conscious awareness of a jump in the target location (countermanding of the pointing action). If there is any way for the visual information guiding the pointing limb to become consciously available, this second response should be sensitive to it.

Method

Eight right-handed university students with normal or corrected-to-normal visual acuity participated in this study after giving informed consent. None of the participants had previously participated in Experiment 1. Participants performed two blocks of 160 trials in a single session. With the exception of the instruction to halt the pointing movement as soon as a "jump" in the target was detected, the methods were identical to Experiment 1.

Results

Six of eight participants always executed their movements to completion (i.e. touched down on the display panel) prior to a countermand. The remaining two interrupted their pointing prior to contact on most trials. Figure 3A shows the accuracy of pointing on all trials on which contact was first made before the action was subsequently countermanded. This analysis shows that pointing accuracy was high, as in Experiment 1, regardless of whether the target remained stationary or jumped. Participants consistently adjusted their pointing to the new location when the target jumped ($F_{(1,5)}$=76.08, P=.001). Distractor jumps again had no influence on pointing (F<1).

Figure 3B shows that verbal reports of object displacement mirrored those found in Experiment 1. Accuracy of jump detection was strongly dependent on object blanking ($F_{(3,21)}$=4.75, P<.01). When only one object blanked it was almost always reported to have jumped ($F_{(3,21)}$=53.09, P<.001). When both objects were blanked, accuracy in detecting the target jump was again above chance (distractor jumped=.58; target jumped=.73), as it was on trials when neither of the objects were blanked (distractor jumped=.64; target jumped=.64).

Action countermanding is also governed by blanking. The results for action countermanding in Fig. 3C show

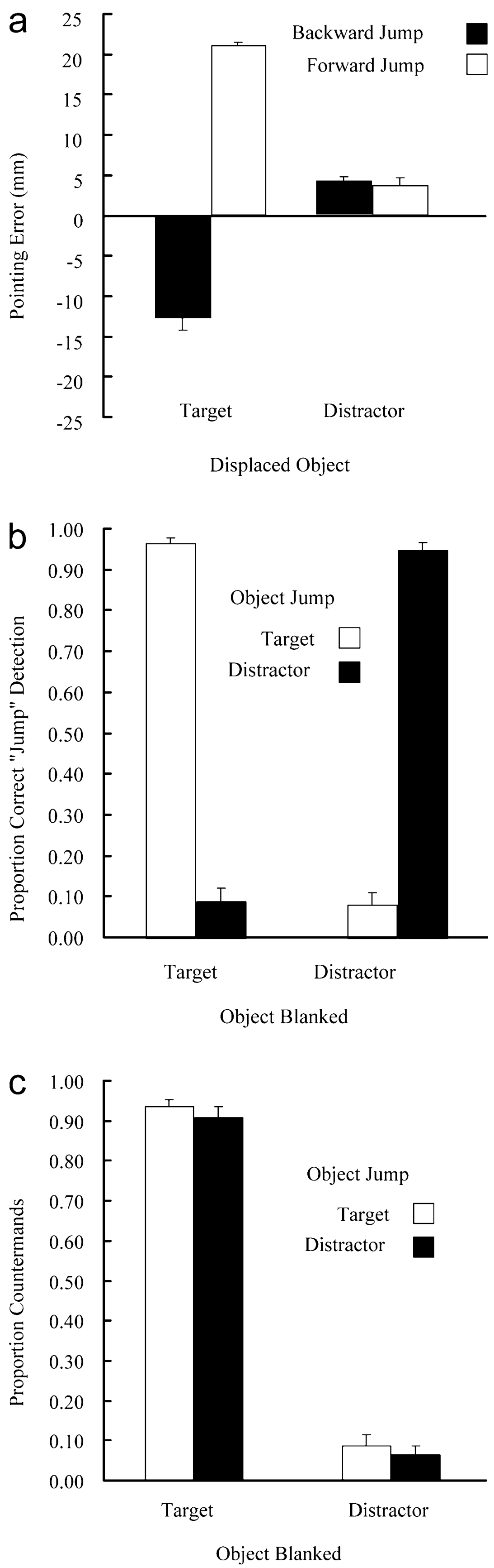

Fig. 3 Pointing accuracy in Experiment 2 relative to the original target location (**a**). Accuracy of the verbal reports in Experiment 2 regarding which of the two objects jumped during the pointing action (**b**). Pointing actions countermanded in response to seeing the target move in Experiment 2 (**c**)

that countermanding was almost entirely governed by whether or not the target object was blanked ($F_{(3,21)}$=46.63, P<.001). Countermanding was observed in more than 90% of the trials when it actually jumped ($F_{(3,21)}$=7.40, P<.01) but it was observed at the same high rate when the target blanked but never moved (difference between conditions, F<1). This meant that participants countermanded pointing movements they had already completed accurately to blanked stationary targets. Moreover, when the target actually jumped, but the distractor blanked and therefore was seen as the displaced object, participants countermanded their pointing less than 10% of the time.

The results for the conditions in which both objects were blanked or neither object was blanked were also consistent with the conclusion that participants were countermanding their actions based on the same information they used to consciously report which object jumped. When both objects were blanked, participants countermanded their responses about 41% of the time when the distractor jumped versus 74% when the target jumped. When neither object was blanked, approximately 37% of responses were halted when the distractor jumped versus 62% when the target jumped.

Countermanding actions were therefore governed by the same information that participants were using to consciously see whether the target or the distractor had been displaced on each trial. None of the information that was guiding the hand was available for use in the countermanding task.

Conclusion

These results clearly indicate that the visual information guiding the hand in a simple pointing task is not accessible to conscious awareness. At the same time that participants are experiencing a visual display in which the target object is actually displaced but appears stationary, their hand is moving to the new target location. Similarly, when they experience a display in which the target is actually stationary but appears to be moving, their hand nonetheless points to the stationary target location. Finally, when participants deliberately try to use the visual information guiding their hand to assist in the determination of whether a target object is stationary or has been displaced, they are unable to do so. Instead, their hand is now guided, correctly or incorrectly, by the visual information used to generate the conscious experience of whether a target has been displaced or not.

This is strong behavioral evidence from healthy adult participants that the neural visual processes used in the on-line control of action are "informationally encapsulated" from processes responsible for the conscious perception of a stable world (Goodale and Humphrey 1998; Milner and Goodale 1995). Previous studies in support of such a dissociation of visually guided action and conscious perception have provided evidence that is more a matter of degree than of kind. For example, the well-known finding that conscious vision is more susceptible to many geometric illusions than are the visual processes guiding reaching and grasping is based on differences of only a few percentage points in illusion magnitude (Bridgeman and Huemer 1998; Haffenden and Goodale 1998). In studies examining the relationship between on-line movement correction and conscious awareness of target displacement, the main finding has been that visual awareness of target displacement *does not interfere* with movement kinematics (Fecteau et al. 2001; Goodale et al. 1986). The present study shows, in addition to these previous findings, that the hand can be guided by visual information that is completely opposed to the visual information used to experience a stable visual world. Moreover, the visual system governing the hand is unable to inform the system governing the conscious eye that this different information is being used to perform its task.

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References

Bridgeman B, Huemer V (1998) A spatially oriented decision does not induce consciousness in a motor task. Conscious Cogn 7:454–464
Bridgeman B, Stark L (1991) Ocular proprioception and efference copy in registering visual direction. Vision Res 31:1903–1913
Bridgeman B, Hendry D, Stark L (1975) Failure to detect displacement of the visual world during saccadic eye movements. Vision Res 15:719–722
Bridgeman B, Lewis S, Heit G, Nagle M (1979) Relation between cognitive and motor-oriented systems of visual position perception. J Exp Psychol Hum Percept Perform 5:692–700
Bridgeman B, Peery S, Anand S (1997) Interaction of cognitive and sensorimotor maps of visual space. Percept Psychophys 59:456–469
Chua R, Elliott D (1993) Visual regulation of manual aiming. Hum Mov Sci 12:365–401
Currie CB, McConkie GW, Carlson-Radvansky LA, Irwin DE (2000) The role of the saccade target object in the perception of a visually stable world. Percept Psychophys 62:673–683
Deubel H, Schneider WX (1994) Can man bridge a gap? Behav Brain Sci 17:259–260
Deubel H, Bridgeman B, Schneider WX (1998) Immediate post-saccadic information mediates space constancy. Vision Res 38:3147–3159
Deubel H, Schneider WX, Bridgeman B (1996) Postsaccadic target blanking prevents saccadic suppression of image displacement. Vision Res 36:985–996
Deubel H, Schneider, WX, Bridgeman B (2002) Transsaccadic memory of position and form. In: Hyönä J, Munoz D, Heide W, Radach R (eds) The brain's eye: neurobiological and clinical aspects of oculomotor research. Elsevier, Amsterdam, pp 165–180
Fecteau JF, Chua R, Franks IM, Enns JT (2001) Visual awareness and the on-line modification of action. Can J Exp Psychol 55:104–110
Goodale MA, Humphrey GK (1998) The objects of perception and action. Cognition 67:181–207
Goodale MA, Pelisson D, Prablanc C (1986) Large adjustments in visually guided reaching do not depend on vision of the hand or perception of target displacement. Nature 320:748–750
Haffenden AM, Goodale MA (1998) The effect of pictorial illusion on prehension and perception. J Cogn Neurosci 10:122–136
Milner AD, Goodale MA (1995) The visual brain in action. Oxford University Press, Oxford
O'Regan JK, Rensink RA, Clark JJ (1999) Change blindness as a result of 'mudsplashes'. Nature 398:34
Pélisson D, Prablanc C, Goodale MA, Jeannerod M (1986) Visual control of reaching movements without vision of the limb II: evidence of fast unconscious processes correcting the trajectory of the hand to the final position of a double-step stimulus. Exp Brain Res 62:303–311
Pisella L, Rossetti Y (2000) Interaction between conscious identification and non-conscious sensori-motor processing. In: Rossetti Y, Revonsuo A (eds) Beyond dissociation: interaction between dissociated implicit and explicit processing. Benjamin, Amsterdam, pp 129–152
Rensink RA (2002) Change detection. Annu Rev Psychol 53:245–277
Simons DJ (2000) Current approaches to change blindness. Visual Cognition 7:1-16
Sperry RW (1950) Neural basis of the spontaneous optokinetic response produced by visual inversion. J Comp Physiol Psychol 43:482–489
von Helmholtz H (1962) Handbuch der physiologischen Optik (1866). Dover, New York
Von Holst E, Mittelstaedt H (1954) Das Reafferenzprinzip. Wechselwirkungen zwischen Zentralnervensystem und Peripherie. Naturwissenschaften 20:464–476