Catching and matching bars with different orientations

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Abstract

The hypothesis that perception enslaves action is examined by assessing whether systematic distortions in perceptual judgments are reflected by inaccuracies in catching. In the first experiment, participants had to align manually the orientation of a reference bar placed at different distances in the frontoparallel plane. In the second experiment participants had to catch differently orientated moving bars, which became invisible at different distances from the interception point. In the matching experiment, systematic errors in the alignment of orientation were found in particular for oblique orientations, the magnitude of which increased with increasing distance of the reference bar. The inaccuracies in the final hand orientation during the catching task, however, did not mirror this pattern of deviations. The findings are interpreted to be more consistent with recent views that vision for perception (i.e., matching) and vision for action (i.e., catching) are dissociated than with the view that perception enslaves action. © 2005 Elsevier B.V. All rights reserved.

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1. Introduction

To date, there has been much work on how we perceive the spatial layout of the world around us. A common observation has been that the Euclidean geometric relations are distorted with respect to distance, location, size, shape, and orientation in the perceived world (Blumenfeld, 1913; Foley, 1980, 1991; Helmholtz, 1962; Hillebrand, 1902; Indow, 1991; Koenderink & van Doorn, 2000; Tittle, Todd, Perotti, & Norman, 1995). It has been observed, for example, that participants show systematic deviations in their perceptual judgements when asked to indicate the halfway point between themselves and a point straight in front of them (Foley, 1967, 1972; Gilinsky, 1951). Concerning orientation, the topic under study here, it has been found that systematic deviations occur when participants are asked to match the orientation of lines or bars in the frontoparallel plane. These deviations appeared larger for oblique orientations than for cardinal orientations, and increased with larger lateral distances of the reference lines or bars (Cuijpers, Kappers, & Koenderink, 2000, 2001; Hermens & Gielen, 2003b; Soechting & Flanders, 1993).

The accurate perception of orientation, distance, and size is often considered indispensable for adaptive actions like grasping and catching objects. This has prompted the issue as to how humans can act accurately (in grasping, catching, and walking) in the face of the observed perceptual distortions. According to one hypothesis, which can be traced back to Descartes (Rossetti, 1998), humans construct from perceptual and cognitive processing one internal representation of the physical environment. This internal representation is thought to form the basis of both conscious experience of the world, and the control of actions (such as grasping, catching, and walking). If this hypothesis is correct, then traces of the perceptual distortion should become apparent in the control of actions. Indeed, there are reports that may be interpreted to support the enslaving hypothesis. Philbeck and Loomis (1997), for instance, found that the distance errors made when walking blindfolded to a remembered target location are related to the errors in perceived distance (cf. Pagano, Grutzmacher, & Jenkins, 2001). Recently, Hermens and Gielen (2003a) have reported similar findings relating to orientation. Participants were presented with a line in various orientations that moved on a vertical screen in the frontoparallel plane towards the participant. The participants were required to align the orientation of a bar with the orientation of the moving reference line at the precise location and time when the line passed in front of the participant. According to Hermens and Gielen (2003a) participants thus intercepted the reference line, and interpreted the task as a catching action. During one condition the line became invisible during its movement. Again, the participants were required to align the orientation of the bar with that of the line at the predefined location at the moment the line would have passed the participant. Participants made significant orientation errors for oblique orientations, but not for cardinal
orientations. Negligible and small orientation errors were made when the line remained visible during its whole movement path. By contrast, in the case that the line became invisible during its approach, larger orientation errors occurred, the magnitude of which increased when the location at which the line turned invisible was further from the interception point. Hermens and Gielen (2003a) showed that these errors were related to errors in perceived orientation of an identical stationary line at various distances. The authors interpreted this analogous pattern of errors as support for the view that perception enslaves action, suggesting that people may not always act accurately.

A different view on how people can act accurately in face of perceptual distortions is the recent proposition of two anatomically and functionally distinct visual streams for perception and action (Bridgeman, Kirch, & Sperling, 1981; Milner & Goodale, 1995; Rossetti, 1998). The dorsal stream is assumed to use visual information to control goal-directed action, whereas the ventral stream is thought to encompass the use of visual information to obtain knowledge of the environment and the self (i.e., perception). Accordingly, the use of vision for perception and action is dissociated. Perceptual distortions, therefore, would not necessarily result in inaccurate actions. Here, a precise description of perception and action is imperative (Rossetti & Pisella, 2002). In that respect, it is the goal of a task, not the movement pattern that is decisive. Perception functions to obtain knowledge of (properties) objects, events and places in the environment (e.g., the orientation of a rod), whereas action functions to change the state of the environment by moving objects or by altering the course of events (e.g., grasping or catching a rod) (Michaels, 2000). The difference between perception and action is sometimes very subtle. Goodale, Milner, Jakobson, and Carey (1991), for example, tested orientation perception of patient D.F. who suffered profound visual agnosia. They found that D.F.’s perceptual judgments were grossly impaired. She was highly variable and made many errors when asked to choose one of the four line orientations that corresponded to the orientation of a slot in a disk, or when requested to turn a hand-held card until its orientation matched that of the slot. In contrast, when she was requested to reach out and post the hand-held card through the slot, the orientation of the card was similar to that of two control participants. In particular, the comparison between the two conditions with the hand-held card is noteworthy. Although both tasks involved a similar pattern of arm movements, the pattern of errors for the perceptual task (i.e., turning the card to match the slot’s orientation) was clearly distinct from that of the action task (i.e., posting the card). It closely resembled the responses of the other perceptual tasks, however. These findings emphasise that it is the task goal and not the absence or presence of movement that sets apart perception and action (for similar findings in healthy participants, see Bridgeman, Gemmer, Forsman, & Huemer, 2000; Bridgeman, Peery, & Anand, 1997; Daprati & Gentilucci, 1997; Dyde & Milner, 2002; Haffenden & Goodale, 1998; Westwood, McEachern, & Roy, 2001). In this respect it is significant that Hermens and Gielen (2003a) had participants align the orientation of a hand-held bar with the orientation of the moving reference line as if to catch the reference line. It is not unlikely that this task, which was used to represent a catching action, might have shared more characteristics with perception tasks (i.e., participants were matching
the orientation of a moving line) than with action tasks (i.e., physically grasping a moving object). If this conjecture is correct, then Hermens and Gielen’s findings cannot be considered to directly support the hypothesis that perception enslaves action. It is not unlikely that both tasks tapped into similar ventral perception processes.

The aim of the present study is to examine whether similar inaccuracies are present in perceptually matching and catching bars presented in different orientations. To this end, two experiments were conducted. Participants were required to either manually match the orientation of a reference bar that was located at different distances (i.e., perception), or to catch differently orientated moving bars that were made invisible at different distances from the interception point (i.e., action). It is expected that if vision for perception enslaves vision for action, distortions in perceived orientation would be reflected in the final hand orientation of the catching movements. Alternatively, distortions in perceived orientation may be unrelated to inaccuracies in the final hand orientation of catching, which would support the contention that vision for perception and vision for action are dissociated processes.

2. Experiment 1: Matching

2.1. Methods

2.1.1. Participants

Ten participants (5 male, 5 female) from 22 to 28 years of age participated in this experiment. Participants reported having normal or corrected to normal vision. All participants were naïve with regard to the task and the purpose of the experiment. After explanation of the nature and the requirements, participants signed an informed consent form in accordance with the policy statement of the local ethical committee.

2.1.2. Task and apparatus

Participants were required to align the orientation of an illuminated target bar (30 cm long and 1.5 cm in diameter) to the orientation of an illuminated reference bar (30 cm long and 1.5 cm in diameter) that was placed at various distances in the frontoparallel plane to the right of the participant. The distance from the eyes to the target bar (and thus from the frontoparallel plane) was 50 cm. The reference bar was presented using the Ball Transport Apparatus (BallTrApp: Fig. 1A). The bar was fixed on a holder that was constructed in such a way that it could be attached to a (moving) lorry, which was fixed to the BallTrApp (see for a detailed description, van der Kamp, Savelsbergh, & Smeets, 1997). The holder was attached to the lorry by means of an air suction system (Fig. 1B). The orientation and location of the reference bar were manually adjusted. The target bar was fixed on a holder in the same way as the reference bar. The holder was attached to an axis, such that the axis of rotation was horizontal and sagittally orientated, allowing the bar to be tilted in the frontoparallel plane, rotating around its centre. The experiment was carried out in the dark, and a LED was placed at one end of both bars, illuminating them from bars from the inside without illuminating the environment.
The orientation of the target bar was obtained using an Optotrak 3020 motion-analysis system (Northern Digital, Waterloo Ontario). Infrared light emitting diodes (IRED’s) were placed on both ends of the bar. The bar orientation was defined as the angle between orthogonal projection of the line connecting the two markers (on the bar) on the frontoparallel plane and the horizontal plane. The data were recorded with a sample frequency of 200 Hz for 1 s.

2.1.3. Procedure and design

Before the beginning of each trial, the participants placed their right hand on a hand rest at waist level 20 cm in front of their body mid-axis. As soon as both bars became visible the participants were allowed to grasp the target bar (which was placed in a random orientation, but never in the same orientation as the reference bar) and to rotate it such that they perceived the target bar to be parallel to the reference bar (i.e., that the orientation of the target matched that of the reference bar). There was no time constraint. After the participants indicated that the bars were perceived as parallel, the orientation of the target bar was recorded.

The orientation of the reference bar had one of four main orientations: horizontal (0° or 180°), oblique (45°), vertical (90°), or oblique (135°), with 0° at 3 o’clock and a positive rotation counter-clockwise. An additional scatter of 2° or 4° was added to these main orientations. For example, the 90° main orientation was presented as
either 86°, 88°, 90°, 92°, or 94°. The participants were told to reproduce the exact orientation of the reference bar. The reference bar was placed at 50 cm, 100 cm, or 150 cm to the right of the participant in the frontoparallel plane. Each trial was repeated 2 times, resulting in 10 repetitions for each main orientation. This resulted in a total of 120 trials (= 4 [main] × 5 [scatter] orientations × 3 distances × 2 repetitions), which were presented in a random order. The experiment took about 1 h.

2.1.4. Data analysis

We used three measures for the difference between the orientation of the reference bar and the target bar: (1) the constant error, defined as the difference in degrees between the orientation of the target bar and the orientation of the reference bar, (2) the absolute error, defined as the absolute difference between the orientation of the target bar and the orientation of the reference bar, and (3) the variable error, defined as the standard deviation for the constant error.

Intra-individual means were calculated from 10 repetitions of each of the 4 main orientations at each of the 3 distances. To reveal perceptual distortions, a series of *T*-tests was carried out to examine whether constant errors differed from zero. The *α*-level was set according to Bonferroni adjustments for multiple comparisons. Furthermore, to reveal systematic differences between the orientations of the reference and target bars each of the three measures was submitted to a 4(orientation: 45°, 90°, 135°, and 180°) by 3(distance: 50, 100, and 150 cm) analysis of variance with repeated measures on both factors. For the case for which the sphericity assumption was violated (i.e., epsilons smaller than 1.0) Huyn–Feldt adjustments of the *p*-values were reported. Finally, post-hoc comparisons were performed with Tukey HSD tests (*p* < 0.05).

3. Results

Two participants (1 male and 1 female) were excluded from the data analysis because of technical failure in the data recording. The remaining eight participants showed similar patterns of results, and hence we only report group averages. Fig. 2 illustrates that the alignment of the orthogonal, but not the cardinal orientations was systematically distorted. *T*-tests confirmed that the constant error differed significantly from zero for the oblique orientations only (indicated by an asterisk). Further analysis of variance on the constant error revealed a significant main effect of orientation (*F*(3, 21) = 55.4, *p* < 0.001). Tukey’s HSD showed that all constant errors at every orientation were significantly different from each other, except for 90° and 180° orientations. The magnitude of the constant errors was larger for oblique orientations as compared to cardinal orientations. Although no main effect of location on constant error (*F*(2, 14) = 0.29) was found, analysis of variance did reveal a significant interaction effect between location and orientation (*F*(6, 42) = 47.7, *p* < 0.001). Tukey’s HSD indicated that the magnitudes of the constant error for the 45° and 135° orientations were larger when the reference bar was located further away. However, for the 90° and 180° orientations the magnitude of the constant error was independent of distance.
A subsequent analysis of variance on the absolute error allowed a comparison between the magnitudes of the errors made for the different main orientations and distances of the reference bar (see Fig. 3). Significant main effects of orientation and location (\(F(3, 21) = 14.4, p < 0.001\); \(F(2, 14) = 47.3, p < 0.001\), respectively) and a significant interaction effect between location and orientation (\(F(6, 42) = 16.5, p < 0.001\)) were found. Tukey’s HSD tests indicated that the magnitudes of the absolute error of the two oblique orientations were significantly larger than that of the two cardinal orientations. A comparison of the two oblique and two cardinal orientations, however, did not indicate significant differences in the magnitude of the absolute error. Finally, the magnitudes of the absolute error were larger for the further reference bar locations for the oblique orientations, but not for the cardinal orientations.
The final analysis assessed the effects on the variable error. Once more, a significant main effect of reference bar orientation was found ($F(3, 21) = 11.4, p < 0.001$). Post-hoc comparisons showed that the magnitudes of the variable error of the two oblique orientations were significantly larger than those of the cardinal orientations. However, the within comparisons of the oblique (i.e., $45^\circ$ vs. $135^\circ$) and cardinal orientations (i.e., $90^\circ$ vs. $180^\circ$) did not reveal differences. Additionally, the variable error appeared significantly affected by location ($F(2, 14) = 7.03, p < 0.001$). Post-hoc comparisons showed a significant difference between the 50 and 150 cm reference bar location. This effect, however, was not mediated by orientation ($F(6, 42) = 0.41$) (see Fig. 4).

4. Discussion

The aim of this experiment was to investigate whether perception of orientation in the frontoparallel plane is distorted. To this end, participants manually aligned the orientation of a target bar to the orientation of a reference bar that was located at different distances. Participants indeed made systematic errors. In the case of the oblique reference orientations, the magnitude of the errors increased with increasing distance of the reference bar. By contrast, the smaller magnitude of the errors for cardinal orientations was not influenced by distance. The current distortions in perceived orientation corroborate previous reports by Hermens and Gielen (2003a, 2003b).

One explanation for the pattern of errors of perceived orientation is that the projection of the orientation of the reference bar on the retina is distorted. If the orientation of an oblique bar in plane $Y$ is projected on plane $Z$ that is not parallel to plane $Y$, the projection of the orientation of the bar on plane $Z$ is distorted. And like in the present experiment, the further the distance between the reference bar and the
projection plane, the larger the distortion in orientation. This geometric distortion is also known as perspective (Hermens & Gielen, 2003b). We assessed to what degree perspective can account for the pattern of errors in perceived orientation of the present experiment. Fig. 5 shows the expected constant errors based upon perspective (see Kanatani, 1990) and the actual constant errors. Qualitatively, the patterns of the observed constant errors resemble those predicted from perspective; the magnitudes of the errors of the oblique orientations (i.e., 45° and 135°) increase with the distance of the reference bar, whereas the magnitude of the errors of the cardinal orientations (i.e., 90° and 180°) are near zero and are independent of the distance of the reference bar (see also Fig. 3). Moreover, geometric distortion predicts the errors for the 45° and 135° orientations to be of the same magnitude but with an opposite sign, which was also found. Nonetheless, it should be pointed out that the magnitude of the observed constant errors is only half of that predicted by perspective, suggesting that the retinal image did not fully specify the orientation of the reference bar.

An alternative explanation for the relatively large magnitude of the errors for the oblique compared with that of the cardinal orientations may be the human visual system’s enhanced sensitivity for horizontal and vertical orientated stimuli as compared to oblique orientated stimuli (Campbell, Kulikowski, & Levinson, 1966; Furmanski & Engel, 2000). The larger variable error for oblique orientations may be a point in case. Despite this finding, the anisotropy in sensitivity for oblique and orthogonal orientations seems a less likely account, because it cannot predict the observed effects of distance on the perceived orientations in case of oblique orientated objects. In sum, it seems that perspective is an important source of information for the perception of orientation. Its use, however, results in systematic errors in perceived orientation.

In Experiment 2, we investigated whether the pattern of errors in perceived orientation was also evident during catching (Hermens & Gielen, 2003a). It is hypothesized that if perception enslaves action, inaccuracies in the final hand orientation of the catching movement would mirror the errors in perceived orientation. Alternatively, if the use of vision for perception and action are separated, the inaccuracies in catching would be unrelated to the errors found for perceived orientation.
5. Experiment 2: Catching

5.1. Method

5.1.1. Participants

Twelve participants (8 male, 4 female), 23–28 years of age participated in this experiment. Six participants had previously taken part in Experiment 1. All participants had normal or corrected to normal vision, were naïve with regard to the purpose of the experiment, and signed, after explanation of the nature and the requirements of the experiment, an informed consent form in accordance with the policy statement of the local ethical committee.

5.1.2. Task and apparatus

The participants were required to catch a moving illuminated bar (30 cm long and 1.5 cm in diameter) that approached with different orientations. The bar approached the participant from the right at eye height in the frontoparallel plane with a speed of 1 m/s. The distance from the eyes to the interception point straight ahead was 50 cm and the bar became visible at 150 cm to the right of the interception point (i.e., the plane in which the bars moved was identical to the plane in which the bars were presented in Experiment 1). The apparatus was similar as in the first experiment (see Fig. 1C). The bar was fixed on a holder, which by means of air suction was attached to a rod connected to the (moving) lorry of the BallTrap (see Fig. 1B). The location and speed of the lorry was determined by a computer-controlled step-motor. When the bar was caught, the bar plus holder was detached from the moving lorry (i.e., the bar became free of the lorry when it was contacted by the catching device (see below)). The experiment was carried out in the dark, and a LED was placed at one end of the bar so as to illuminate the bar from the inside without illuminating the environment.

To spatially constrain the participants’ final hand orientation, the participants wore a catching device (see Fig. 1D). The device consisted of two plates (22 cm high and 14 cm wide) that were connected to each other by a hinge. The fingers were strapped to one of the plates and the thumb was strapped to the other plate, the hinge was in the palm of the hand. The bar could only be grasped successfully if the device was accurately aligned with the orientation of the bar.

The position and orientation of the bar and the catching device were obtained using an Optotrak 2030 motion-analysis system (Northern Digital, Waterloo Ontario). IREDs were placed on both ends of the bar and on both ends of the back (formed by the hinges between the two plates) of the catching device. The kinematic data were recorded at a sample frequency of 200 Hz.

To detect the moment of contact between the catching device and bar, the bar was covered with a conducting mesh and the inside of the catching device was covered with conducting foam, both of which were connected by a wire. As soon as contact was made between the catching device and the bar, an electrical circuit was closed and an Optotrak IRED was turned on. This indicated the moment of completion of the catch.
5.1.3. Procedure and design

To familiarize themselves with the task and the catching device, the participants started with four practice trials in which the bar was visible during the whole trajectory. The participants placed their right hand, strapped in the catching device, in a resting location at waist level 20 cm in front of their body mid-axis. At the beginning of each trial the participants had to look to a LED near the starting position of the bar. One second after the LED was turned off the bar started to move (with 1 m/s) and became visible at 150 cm to the right of the participants. The bar moved with one of four orientations; 180°, 135°, 90° or 45°, with 0° at 3 o’clock and a positive rotation counter-clockwise. The bar either became invisible (by turning off the LED that illuminated the bar) at 50 cm before the interception point, or remained visible during the whole trajectory. The participants were not informed that the bar was made invisible. Each orientation was repeated 10 times. This resulted in a total of 80 trials (= 4 orientations × 2 visibility locations × 10 repetitions), which were randomly presented. The experiment took about 45 min.

5.1.4. Data analysis

The orientation of the catching device was defined as the angle between orthogonal projection of the line connecting the two pairs of IREDs on the catching device on frontoparallel plane and the horizontal. The final hand orientation of the catch was defined as the orientation 10 ms before the catching device contacted the bar.

We used three measures to assess the accuracy of the final hand orientation during catching (1) the constant error, defined as the difference between the orientation of catching device and the orientation of the catching bar, (2) the absolute error, defined as the absolute difference between the orientation of catching device and the orientation of the catching bar, and (3) the variable error, defined as the standard deviation of the constant error.

Intra-individual means were submitted to a 2(viewing; visible throughout vs. visible until 50 cm distance) × 4(orientation: 45°, 90°, 135°, and 180°) analysis of variance with repeated measures on both factors. For the case for which the sphericity assumption was violated (i.e., epsilons smaller than 1.0) Huyn–Feldt adjustments of the p-values were reported. Post-hoc comparisons were performed with Tukey HSD tests (p < 0.05).

6. Results

Two participants (1 male and 1 female) were excluded from the data analysis because of technical failure in the data processing. Both participants had participated in Experiment 1. The remaining 10 participants successfully caught the moving bar: there were only four trials in which participants failed to catch the bar. Fig. 6 shows the average constant errors of the 10 participants.

Significant main effects of viewing and orientation were found for constant error (F(1, 9) = 5.20, p < 0.05 and F(3, 27) = 4.97, p < 0.01, respectively). In addition, the viewing by orientation interaction was significant (F(3, 27) = 3.41, p < 0.05). Tukey’s
HSD tests showed that the constant error for the 180° orientation differed from that for the 45° and 90° orientation. In addition, making the bar invisible resulted in a significantly larger magnitude of the constant error for the 45° orientation only (Fig. 6).

Subsequent analysis on the absolute error revealed a significant effect of viewing ($F(1,9)=17.6, p<0.01$), showing that the magnitude of the absolute error increased when the bar became invisible at 50 cm before the interception point (Fig. 7). The orientation and viewing by orientation effects did not reach significance. Analysis of the variable error revealed neither significant effects for viewing and orientation, nor for their interaction (Fig. 8).

6.1. Comparing Experiments 1 and 2

Next we compared the pattern of orientation errors in the two experiments. To this end, the constant error observed in the 50 cm distance condition of the matching task was compared to the difference in constant error between the two viewing conditions (i.e., the error for the catching bar visible until 50 cm condition minus the error
for bar visible throughout the condition) of the catching task. The latter measure, denoted further as the constant catching error, was chosen because even when the moving bar was visible throughout its trajectory constant errors were large, indicating that even when directly in front of the participant, the final orientation of the catching device had an offset with respect to the orientation of the catching bar.\footnote{For the matching task, we assume that participants would have aligned the orientation of the target bar almost perfectly to the orientation of the reference bar in a straight line in front of them.} Fig. 9 shows the average constant matching and catching errors. The patterns of constant errors for the two tasks appear rather disparate.

A 2(task: matching vs. catching) by 4(orientation: 45°, 90°, 135°, and 180°) analysis of variance with repeated measures on the last factor indeed yielded a significant orientation by task interaction ($F(3, 48) = 10.6, p < 0.001$). Tukey’s HSD test showed that the magnitude of the constant matching error differed between the 45°, 135° and 90° and 180° orientations. By contrast, the magnitude of the constant catching...
error was not different between orientations. This finding was supported by observations of the individual data. As mentioned above, the pattern of constant matching errors was similar across participants for the matching task. However, there were large individual differences for the pattern of constant error in the catching task, with only one participant showing a pattern of errors that mirrored that in the matching task.

7. Discussion

The aim of the second experiment was to investigate whether orientation-dependent errors could be discerned in catching, and if so, whether these reflect those found for perceived orientation. It is found that orientation-dependent errors also occur when catching moving bars. In particular, the findings indicate that for the 45° orientation, the final hand orientation is orientated more to the vertical when the bar is not visible until the interception point than when the bar remains visible throughout its movement. In addition, the absolute error is larger when the bar is not visible throughout its trajectory, independent of the orientation of the bar. Unlike for the matching task, no systematic differences between oblique and orthogonal orientations are apparent.

Neither the geometric distortion (i.e., perspective) nor a difference in the sensitivity for horizontal and vertical orientations offer a simple explanation for the observed pattern of errors. Geometric distortion would have predicted an increase in constant error for the oblique orientations, but not for the cardinal orientations, when the bar is made invisible before the interception point. Moreover, the signs of the constant errors for the two oblique orientations would have been expected to be opposite. Anisotropy in sensitivity for oblique and cardinal orientations would have resulted in larger variable errors for the oblique orientations. However, there is not even a qualitative agreement with one of these explanations. It seems, therefore, more likely that motor or action constraints have had a larger impact on the final hand orientation than the exploitation of any of these sources of visual information. We come back to this issue later.

8. General discussion

The main purpose of the current study is to assess the hypothesis that perception enslaves action. Although systematic errors were distinguished in the matching and catching tasks, the orientation errors in matching were not reflected in catching, in particular so for the oblique orientations. The patterns of orientation errors in matching and catching are unrelated. This was true for all participants, except one. We conclude, therefore, that the present experiment does not provide evidence that perception enslaves or uniquely determines action.

The analysis for the absolute errors showed a similar pattern.
One reservation to this conclusion that might be raised is that the processes of perception and action might still be causally related, even if the patterns of constant and absolute errors are not similar. That is, it is not inconceivable that perception is followed by an additional process that ‘removes’ the perceptual distortion to prevent action from being inaccurate. The consequence would be an increased variable error for action induced through noise associated with the additional processing (Michaels, Withagen, Jacobs, Zaal, & Bongers, 2001). At first glance, the larger variable error in catching compared to matching may lend support to this hypothesis. Another finding, however, renders this explanation less likely. The most pronounced differences between the matching and catching tasks were found for the oblique orientations. Hence, the most additional processing would be needed for the oblique orientations, and hence the difference in variable error for the oblique and cardinal orientations is expected to be larger in catching than in matching. By contrast, a difference in variable error in catching between the oblique and cardinal orientations was not found.

Hermens and Gielen (2003a) reported that both for matching and catching the constant errors in the oblique orientation increase with distance of the static reference object or the distance at which the moving reference object becomes invisible. We did not replicate the oblique effect for the final hand orientation in catching when the bar becomes invisible at a distance from the interception point, presumably because the constraints in our catching experiment were (and were meant to be) vastly different from those in the work of Hermens and Gielen (2003a). Instead of mimicking a catch by aligning a hand-held bar with the orientation of a moving reference line (i.e., perception), participants in the current study moved to actually intercept and grasp a physical bar (i.e., action). Whereas Hermens and Gielen compared two perceptual tasks, in which participants had to match the orientation of stationary and moving lines, we contrasted a perceptual task with an action task. Hermens and Gielen found a similar pattern of orientation errors in the two perceptual tasks. The current study replicated this pattern for the perceptual task, but not in the action task. Taken together these findings are indeed consistent with the proposal that vision for perception and action are dissociated (e.g., Milner & Goodale, 1995). The present results, however, do not necessarily prove the putative dissociation.

The dissociation between vision for perception and action is assumed to encompass the use or processing of different sources of information (e.g., Milner & Goodale, 1995; van der Kamp, Oudejans, & Savelsbergh, 2003). Compared to the control of action, perceptual judgments are thought to rely much more on pictorial sources of information, such as relative size and texture. The current study shows that perspective, another example of a pictorial information source, seems a powerful variable in the specification of perceived orientation, but not in the control of hand orientation during catching, in which alternative or additional information sources may have been involved. The information may be embedded in the invariant transformations of the optic flow field that are generated by the motion of the bar (Gibson, 1979). The projection of the orientation of a stationary bar on the retina is distorted, and the further the distance, the larger the distortion (i.e., perspective). The retinal orientation, however, changes when the bar moves and passes in the frontoparallel plane. If
the observer can extract information on the bar’s current speed and distance, then the rate of change of the retinal orientation would provide information about the moving bar’s (future) orientation. A study by Mitsumatsu and Yokosawa (2003) provides some evidence that people are sensitive to this type of information. Participants indicated whether objects that passed and moved in their frontoparallel plane and that were temporally occluded, were the same or different. The participants responded slower when the rate of change of retinal orientation was unpredictably changed during the occlusion period (i.e., inconsistent with a constant orientation of the moving bar). In order to avoid any misunderstanding, it is pertinent to note that Mitsumatsu and Yokosawa’s study involved a perceptual task and did not ask the participants to indicate the orientation of the objects. It does suggest, however, that object motion may grant additional information about an object’s (future) orientation. Yet, Hermens and Gielen (2003a) found the same pattern of orientations errors for static and moving lines, suggesting that the information did not contribute to the perception of orientation. Whether or not the rate of change of retinal information is actually involved in the control of the hand orientation during catching remains an empirical issue.

Another information-based difference between perception and action may be the greater sensitivity of the visual system for cardinal orientations as compared to oblique orientations in the matching task and not in the catching task, as indicated by the pattern of variable errors. This visual oblique effect is thought to originate in the primary visual cortex (Furmanski & Engel, 2000; Li, Peterson, & Freeman, 2003), and has been observed with measures such as a spatial acuity test, contrast sensitivity, orientation sensitivity, orientation discrimination and motion discrimination. If the oblique effect has its neural basis in primary visual cortex than one would expect that the oblique effect would materialize in both perception and action. However, this oblique effect has not been observed in action tasks, underlining that perception and action may rely differently on similar sources of information.

In addition, one could argue that also motor constraints and not only the visual constraints make the difference between perception and action. Obviously, the final hand and arm orientation depends on orientation of the target (Desmurget & Prablanc, 1997), but others have found that the final orientation is also affected by intrinsic (i.e., arm posture) constraints (Soechting & Flanders, 1993; Wang, 1999). Wang (1999), for instance, argues that the contribution of each individual joint to an arm movement is constrained by the principle of minimum energy and minimum discomfort. The actual movement then is assumed to reflect the balance between the comfort postures that the arm tries to hold and the recruitment of additional degrees of freedom enforced by task demands (Paulignan, Frak, Toni, & Jeannerod, 1997). Hence, one may speculate that the inaccuracies in the final hand orientation in catching, that is the observation that the final hand orientation was not precisely aligned with the orientation of the moving bar, serve to keep the shoulder, arm and wrist joints within their range of comfort. Nevertheless, comfort of the end posture is not the only motor constraint on the final hand orientation. For a successful interception, the rotation of the hand during the catching movement will be an important constraint for the final hand orientation.
Meulenbroek, Rosenbaum, Jansen, Vaughan, and Vogt (2001) found that a major determinant of grasping kinematics is avoidance of collisions with the object to be grasped. In the case of catching, for instance, it is important not to collide with the object before the hand is in the right orientation. Hence, adjustment of the orientation of the hand (grasping device) must take place before the hand is in the movement plane of the bar. Thus unlike matching, the change in orientation needs to be controlled throughout the catch to arrive with the correct orientation at the right place and time. The relatively large variable error in the final hand orientation may have resulted from these or similar continuous control processes.

In short, motor constraints are likely to have had a much greater impact on the hand orientation in the catching than in the matching task. If this conjecture is correct, then it would follow that the different pattern of errors in catching and matching are not only due to visual constraints, but also to motor constraints. Having said this, however, it must be remembered that getting the hand in an appropriate orientation at the right place and time assumes the detection and use of visual information (Peper, Bootsma, Mestre, & Bakker, 1994).

We conclude that the systematic distortions in perceived orientation are not reflected in the control of the final hand orientation. It is suggested that the results are consistent with recent models purporting a dissociation between vision for perception and vision for action. However, it is argued that motor constraints also need to be taken into account.

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