Atten Percept Psychophys (2013) 75:1206–1214
DOI 10.3758/s13414-013-0476-3

Dissociations between vision for perception and vision for action depend on the relative availability of egocentric and allocentric information

Rouwen Cañal-Bruland · Frank Voorwald · Kirsten Wielaard · John van der Kamp

Published online: 14 May 2013

Abstract In three experiments, we scrutinized the dissociation between perception and action, as reflected by the contributions of egocentric and allocentric information. In Experiment 1, participants stood at the base of a large-scale one-tailed version of a Müller-Lyer illusion (with a hoop) and either threw a beanbag to the endpoint of the shaft or verbally estimated the egocentric distance to that location. The results confirmed an effect of the illusion on verbal estimates, but not on throwing, providing evidence for a dissociation between perception and action. In Experiment 2, participants observed a two-tailed version of the Müller-Lyer illusion from a distance of 1.5 m and performed the same tasks as in Experiment 1, yet neither the typical illusion effects nor a dissociation became apparent. Experiment 3 was a replication of Experiment 1, with the difference that participants stood at a distance of 1.5 m from the base of the one-tailed illusion. The results indicated an illusion effect on both the verbal estimate task and the throwing task; hence, there was no dissociation between perception and action. The presence (Exp. 1) and absence (Exp. 3) of a dissociation between perception and action may indicate that dissociations are a function of the relative availability of egocentric and allocentric information. When distance estimates are purely egocentric, dissociations between perception and action occur. However, when egocentric distance estimates have a (complementary) exocentric component, the use of allocentric information is promoted, and dissociations between perception and action are reduced or absent.

Keywords Goal-directed movements · Dorsal stream · Ventral stream · Allocentric information · Egocentric information · Exocentric · Perception · Action

Empirical evidence seems to abound supporting the proposal that the visual system comprises two neuroanatomically and functionally separate but interacting systems, in which the ventral stream serves "vision for perception" and the dorsal stream serves "vision for action" (Goodale & Milner, 1992; Milner & Goodale, 1995). However, behavioral and neurophysiological findings have been reported that put in question a clear-cut separation between vision for perception and vision for action, thereby sparking debate about the two-visual-systems model proposed by Milner and Goodale (Bruno, 2001; Glover, 2004; Milner & Goodale, 2008). The aim of this article is to further examine the role of vision for perception and action. To this end, in three experiments we asked participants to perform either a perceptual judgment task or a motor task (i.e., throwing a beanbag) toward the end location of the shaft of a large-scale Müller-Lyer illusion (with hoops instead of arrows as its tails).

Visual illusions have been extensively used to examine dissociations between vision for perception and vision for action (for meta-analyses and reviews, see Bruno, Bernardis, & Gentilucci, 2008; Bruno & Franz, 2009; Bruno, Knox, de Grave, 2010; Milner & Goodale, 2008). Aglioti, DeSouza, and Goodale (1995) were the first to report that when participants were asked to grasp the inner circle of an Ebbinghaus illusion configuration, their actions (more specifically, their maximum grip apertures) were not affected by the illusion, whereas verbal judgments of the size of the inner circle

R. Cañal-Bruland (✉) · F. Voorwald · K. Wielaard · J. van der Kamp
Faculty of Human Movement Sciences, MOVE Research Institute Amsterdam, VU University Amsterdam, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands
e-mail: r.canalbruland@vu.nl

J. van der Kamp
Institute of Human Performance, University of Hong Kong, Hong Kong SAR, China

showed the typical illusion effects (for similar results, see Haffenden & Goodale, 1998). These and similar findings have been interpreted to support the basic assumptions underlying the two-visual-systems model: The first of these is that vision for perception serves to encode objects' sizes and distances relative to environmental features. Accordingly, vision for perception entails the use of allocentric sources of information, and therefore is susceptible to visual illusions. Also, it is assumed that vision for action subserves the control of movements, and therefore processes absolute rather than relative metrics. Action therefore relies on egocentric information sources, and consequently is not susceptible to visual illusions.[1]

Expanding on the work of Aglioti et al. (1995), Wraga, Creem, and Proffitt (2000, Exp. 2) reported a dissociation between vision for perception and vision for action for whole-body movements. In their second experiment, participants were invited to stand at the endpoint of a line at the other end of which a single hoop emulated the one-tail configuration of a Müller-Lyer illusion (for an identical setup, see Fig. 1). This setup was chosen to promote an "egocentric frame of reference" (Wraga et al., 2000)—that is, to increase the availability and use of egocentric information specifying target distance. In a between-subjects design, participants were asked either to estimate and verbally indicate the extent of the line or to turn 90º to their left and walk the same distance while blindfolded. Both tasks were performed with four different line lengths and in both hoop-in and hoop-out configurations. The results revealed a dissociation between the verbal judgment and the blind-walking measure: Whereas the verbal judgments were biased by the illusion, the blind-walking measure was not. This led the authors to conclude that when participants were provided with an egocentric task, vision for perception and vision for action dissociated.

However, to what degree blind-walking can be considered an "action" measure may be questioned. Milner and Goodale (2008, p. 778) recently argued that "the fact that a task involves action does not mean that the performance of this task would engage vision for action." In their critique of a study of Schenk (2006), they argued that a manual matching task in which the participant is asked to move a finger to an arbitrary point is nothing else but a "manual report" of a perceptual estimate (Milner & Goodale, 2008). A similar argument can be made about blind-walking as an action measure. Here, we argue that blind-walking may be considered a "gait report" of a perceptual estimate of extent.

The main argument for using blind-walking as an action measure is that actions need to be executed in an open loop—that is, without visual feedback—to prevent the actor from making visually guided and environment-informed adjustments to the movement as it unfolds (Wraga et al., 2000). This reasoning has led experimenters to blindfold participants in matching tasks of extents (e.g., walking a certain distance), and perhaps even in near-aiming tasks (e.g., pointing or grasping). However, occluding vision may disrupt the participants' responses in a variety of unknown ways. In far-aiming tasks, such as when throwing an object (e.g., a beanbag) toward a distant target location, it is not necessary to blindfold participants. After release of the object, the actor can no longer exploit visual or proprioceptive information to influence or adjust the object's trajectory, thereby rendering the blindfold redundant (Glover & Dixon, 2004; see also Caljouw, van der Kamp, & Savelsbergh, 2010; van der Kamp, van Doorn, & Masters, 2009). In addition, it is reasonable to argue that a task such as throwing a beanbag toward a target location would by definition tap into vision for action, as vision for action is required to control the target-directed movement (cf. van der Kamp et al., 2009). It logically follows that a visual illusion, such as the one-tailed Müller-Lyer illusion used by Wraga et al. (2000), should have no effect if participants stood at the beginning of the shaft and were to throw an object toward the end location of the shaft.

To test this contention and to further examine dissociations between vision for perception and action, we conducted three experiments. On the basis of the study by Wraga et al. (2000), in Experiment 1 participants were presented with a large-scale one-tailed version of a Müller-Lyer illusion and asked either to throw a beanbag to the end location of the corresponding line (i.e., shaft) or to provide a verbal estimate of the egocentric distance to that location. When performing these tasks, participants stood at the beginning point of the shaft of the Müller-Lyer configuration (i.e., opposite to the end location; see Fig. 1). In keeping with the distinction between vision for perception and vision for action, and with the associated use of allocentric and egocentric information, we predicted that the illusion would show an effect on the verbal estimates, but not on the throwing task.

In Experiment 2, we changed the layout to a regular two-tailed version of the large-scale Müller-Lyer illusion, as the two-tailed configuration is known to increase the strength of the illusion (Wraga et al., 2000). In addition, in each trial participants stood at a distance of 1.5 m from the beginning of the shaft (for an identical setup, see Wraga et al., 2000). When the participants stood at a distance from the illusion

[1] In line with an ecological perspective on perception and action (Gibson, 1986), we refer to "the use of allocentric and egocentric information" (see Michaels, 2000). This diverges from Milner and Goodale (1995, 2008), who adhered to a more constructivist perspective when they referred to the "processing of visual input into allocentric or egocentric frames of reference." Although the ecological and constructivist approaches differ fundamentally in their theoretical assumptions, for the present purposes the reader may substitute *processing of information* for *use of information*, should he or she be so inclined.

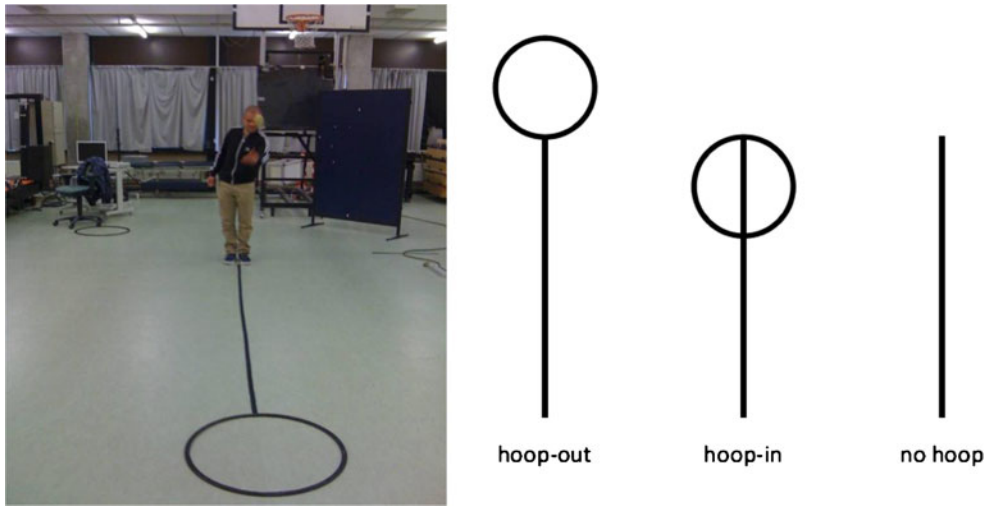

Fig. 1 Example of the action task in the one-tailed Müller-Lyer configuration of Experiment 1 (left), and schematic illustrations of the three conditions (hoop out, hoop in, and no hoop; right)

rather than on it, the tasks could also be performed by combining egocentric (i.e., distance from the participant's vantage point to the base of the Müller-Lyer shaft) and exocentric (i.e., distance from the base of the Müller-Lyer to the endpoint of the shaft) distances. The exocentric distance component makes additional allocentric information available on which participants can rely to base their responses. Potentially, this allows for a more powerful test of the robustness of vision for action with respect to the illusion. As in Experiment 1, participants were asked either to perform a beanbag-throwing task or to provide verbal estimates while standing outside of the two-tailed illusion. In line with Milner and Goodale's two-visual-systems model (Goodale & Milner, 1992; Milner & Goodale, 1995, 2008), in Experiment 2 an illusory bias larger than that in Experiment 1 was expected on the perceptual estimates, but not on the throwing performance. Alternatively, it might also be assumed that participants would exploit all available sources of distance information (including the complementary exocentric distance component). If this conjecture is correct, the corresponding increase in the availability of allocentric information would also lead to an effect of the illusion on action, resulting in a less pronounced dissociation between perception and action than in Experiment 1.

In Experiments 1 and 2, we replicated the original two experimental setups used in Wraga et al. (2000). Importantly, this meant that in Experiment 2 we made two adjustments to the experimental setup—namely, a change to the configurations (two-tailed illusions in Exp. 2 vs. one-tailed illusions in Exp. 1) and a change to the position of the participant (standing at a distance of 1.5 m from the beginning of the shaft of the illusion in Exp. 2 vs. standing at the beginning of the shaft in Exp. 1). However, due to this confound, potentially different results would be difficult to attribute to the change in the configuration, the position of the participants, or both. Hence, Experiment 3 was a replication of Experiment 1 with one difference; that is, a one-tailed version of a Müller-Lyer illusion was used, but participants stood at a distance of 1.5 m from the illusion, as in Experiment 2.

Experiment 1

In Experiment 1, we examined whether the dissociation between vision for perception and vision for action would be apparent when comparing a verbal estimation task with a throwing task. To this end, participants were presented with a large-scale one-tailed version of a Müller-Lyer illusion and asked either to throw a beanbag to the end location of the shaft or to provide a verbal estimate of the egocentric distance to that location while standing at the beginning of the shaft. On the basis of the two-visual-systems model (Aglioti et al., 1995; Milner & Goodale, 1995), we predicted that the illusion should show an effect on the verbal estimates, but not on the throwing task.

Method

Participants A group of 30 right-handed participants (M = 24.8 years, SD = 5.5; 13 male and 17 female) volunteered to take part in the experiment. The participants provided informed consent and were free to withdraw from testing at any time. The experiment was conducted in accordance with the ethical guidelines of the local institution.

Apparatus and stimulus As in Wraga et al. (2000), black ribbon lines of four different lengths (175, 225, 275, and 325 cm) and 2 cm in width were used to create the shafts of the Müller-Lyer illusion configurations. One black hoop with an internal diameter of 64 cm (with a line 2 cm in width) served as a single tail of the illusion, pointing either inward (hoop-in configuration) or outward (hoop-out configuration) from the end location of the shaft. Using the ribbon lines without a hoop served as a control condition.

In total, 12 different configurations (four line lengths by three illusion configurations [hoop in, hoop out, and no hoop]) served as stimuli (for a schematic illustration of the three configurations, see Fig. 1). A filled rubber glove served as the beanbag to be used as the throwing object.

Procedure After participants had provided informed consent and filled in a short questionnaire about demographic information, they were randomly assigned to either a motor task group (n = 15) or a perceptual estimate task group (n = 15). The reason for using a between-subjects design was to ensure that perceptual estimates did not affect actions, and vice versa. Independent of group, each participant observed 12 different setups, including eight one-tailed Müller-Lyer illusion configurations (four line lengths by two configurations, hoop in and hoop out) and four line lengths with no hoop present (control condition), in random order. Participants performed one trial for each of the 12 setups, to ensure that their throws were not influenced by knowledge of the results. In both groups, participants were instructed to stand directly at the beginning of the ribbon line.

In the verbal estimate task, participants were instructed to indicate the egocentric distance to the endpoint location of the shaft in either centimeters or meters (i.e., to indicate the distance from themselves to the endpoint location of the shaft). In the motor task, participants were instructed to throw the beanbag towards the endpoint location of the shaft—that is, to try to hit the endpoint location (for an example of the motor task with a hoop-out configuration, see Fig. 1).

In both tasks, after each attempt participants had to shortly position themselves behind a wall so that they could not see the experimenters measuring the outcome and preparing the following configuration. When the next configuration was arranged, the experimenter invited the participant to position her- or himself again at the beginning of the ribbon line for the next trial.

Data analysis First, to determine the effects of the hoop-in and hoop-out illusions on the verbal estimates and the throwing distances in the longitudinal axis (i.e., the length of the ribbon line plus the over- or undershot) in centimeters, the outcome measures of the control condition were subtracted from the outcome measures in the hoop-in illusion (effect of the hoop-in illusion) and from the outcome measures of the hoop-out illusion (effect of the hoop-out illusion) across the four different line lengths (for examining the magnitudes of the tails-in and tails-out illusions relative to the control condition [i.e., no tails], see, e.g., Welch, Post, Lum, & Prinzmetal, 2004). Second, the mean slopes (across the illusion and control conditions) for the length estimates for both the verbal and the motor tasks were separately calculated for each participant. As a third step, the effects of the illusion for both the hoop-in and hoop-out illusions for each participant were adjusted for the mean individual slopes (i.e., divided by the mean individual slopes; for the necessity to correct for potentially different slopes of the perception and action measures, and for different methods to achieve this, see Franz, Fahle, Bülthoff, & Gegenfurtner, 2001; Stöttinger & Perner, 2006).

The adjusted effects of the illusion were then subjected to a 2 (illusion: hoop-in and hoop-out) × 2 (task: verbal and motor) mixed-design analysis of variance (ANOVA). The effect sizes were calculated using partial eta-squared values (η_p^2). The alpha level for significance was set at .05. Mauchly's test of sphericity revealed no violations of the sphericity assumption. Levene's test showed that the variances of both dependent measures were equal across groups (both $ps > .28$). To further examine the significant interaction effects, t tests were administered.

Results and discussion

The ANOVA revealed a significant main effect of illusion, $F(1, 28) = 9.727$, $p = .004$, $\eta_p^2 = .258$, but no main effect of task, $F(1, 28) = 0.395$, $p = .535$, $\eta_p^2 = .014$. Importantly, however, we observed a significant interaction between illusion and task, $F(1, 28) = 9.507$, $p = .005$, $\eta_p^2 = .253$ (see Fig. 2). Post hoc comparisons indicated that in the verbal task, the predicted underestimations of distance (–5.40 cm) for the hoop-in illusion and the predicted overestimations (8.95 cm) of distance for the hoop-out illusion differed significantly, $t(14) = 4.75$, $p < .001$. Yet, in the motor task, the illusions had no differential effect, $t(14) = 0.023$, $p = .982$.

The results thus support theoretical grounds that argue in favor of a dissociation between vision for perception and vision for action (Goodale & Milner, 1992; Milner & Goodale, 1995). As is predicted by these accounts, when participants stood at the beginning of the ribbon line and faced the one-tailed Müller-Lyer configuration, this resulted

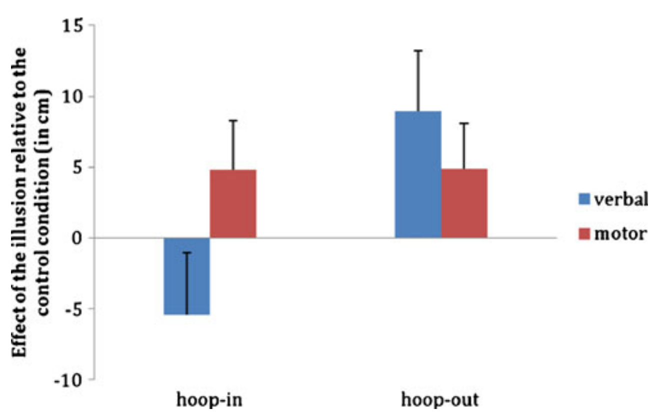

Fig. 2 Mean illusion effects of the hoop-in and hoop-out configurations (adjusted for the mean individual slopes, in centimeters) relative to the control condition (i.e., no hoop) for both tasks (verbal and motor) in Experiment 1. Bars indicate the standard errors of the means

in the presence of the typically observed illusory effects on the verbal estimates and the absence of the effect on the throwing task.

Experiment 2

An assumption within the two-visual-systems model is that for a given perception or action task, observers and actors use either allocentric or egocentric sources of information, but not at the same time (Goodale & Milner, 1992; Milner & Goodale, 1995).[2] However, when both sources of information are concurrently available, it may be that differences in the illusion effects originate from the different relative contributions of allocentric and egocentric information, depending on their availability relative to the task. Possibly, if task constraints increase the availability of allocentric information, the illusion might not only bias perception, but affect action as well. For example, in distance perception, two components can be distinguished: exocentric distance, or the absolute distance between two locations external to the observer, and egocentric distance, which is the relative distance between the observer and an external location. Loomis, da Silva, Fujita, and Fukusima (1992; see also Loomis, da Silva, Philbeck, & Fukusima, 1996) showed that the perceptions of the two components are—to a certain degree—dissociated. In terms of information usage, the egocentric, absolute distances are specified by egocentric information, whereas exocentric relative distances most likely involve allocentric information. Hence, in Experiment 2 we added an exocentric component to the egocentric distance tasks of Experiment 1. If this indeed enhances the relative availability of allocentric over egocentric information, this would allow for a stronger test of the dissociation between perception and action.

This conjecture was tested by having the participants stand at a distance of 1.5 m from the base or beginning of the shaft of the Müller-Lyer illusion (for an identical setup, see Wraga et al., 2000). That is, whereas the tasks in Experiment 1 were entirely egocentric, for Experiment 2 we created an additional exocentric distance component. This allowed the perception and action tasks to also be performed by using egocentric information, specifying the distance between the participant and the base of the shaft, complemented by allocentric information that specified the distance between the base and the endpoint of the shaft (i.e., the exocentric component). Obviously, the tasks could still—as in Experiment 1—be solved by using only egocentric information that specified the absolute distance between the participant and the end of the shaft. However, if participants exploit all available sources of information when perceptually estimating the distance to a target location, one would expect that with the greater availability of allocentric information, an effect of the illusion would arise not only in perception, but also in action. Under this scenario, a less pronounced dissociation between perception and action, as per Experiment 1, would be expected. In addition, because the illusion effect has been shown to increase with two hoops (see Wraga et al., 2000), we attempted to further enlarge the illusion effect by using a regular two-tailed version of the Müller-Lyer configuration.

Method

Participants A group of 30 right-handed participants (M = 23.7 years, SD = 7.6; 10 male and 20 female) who had not participated in Experiment 1 volunteered to take part in Experiment 2. These participants provided informed consent and were free to withdraw from testing at any time. The experiment was conducted in accordance with the ethical guidelines of the local institution.

Apparatus and stimulus The materials were the same as those in Experiment 1, with the difference that in Experiment 2 a regular two-tailed Müller-Lyer illusion configuration was used. Therefore, two black hoops with a diameter of 64 cm (line 2 cm in width) served as the tails of the illusion. The hoops pointed either inward (hoops-in configuration) or outward (hoops-out configuration) from the end location of the shaft. Using the ribbon lines without hoops served as a control condition. As in Experiment 1, 12 different configurations (four line lengths by three illusion configurations [hoops in, hoops out, and no hoops]) served as stimuli. The rubber glove (i.e., beanbag) used in the first experiment also served as the throwing object in Experiment 2.

Procedure The procedure was similar to that of Experiment 1. After participants provided informed consent and filled in a short questionnaire, they were randomly assigned to either a motor task group (n = 15) or a perceptual estimate task group (n = 15). Independent of group, each participant took part in the 12 different configurations of illusion and line length, in random order. In contrast to Experiment 1, and as in Wraga et al. (2000, Exp. 1), participants stood 1.5 m from the beginning of the ribbon line (i.e., the endpoint of the shaft closest to them).

In the verbal estimate task, participants were asked to indicate the egocentric distance to the endpoint location of the ribbon line farthest from them in either centimeters or meters. In the motor task, participants were asked to throw the beanbag toward the endpoint location of the ribbon line farthest from them. In both tasks, after each attempt

[2] Note that from a constructivist perspective, this would be referred to as the *processing* or *encoding* of information within only one frame of reference.

participants had to shortly position themselves behind a wall so that they could not see the experimenters measuring the outcome and preparing the following configuration. When the next configuration was arranged, the experimenter invited the participant to position her- or himself again at a distance of 1.5 m from the beginning of the ribbon line for the next trial.

Data analysis The data analysis was identical to that in Experiment 1. In Experiment 2, one participant's response to the hoop-out illusion in the throwing task was identified as an outlier (more than 3 *SD*s below the mean) and was consequently removed from further analyses. Note that we also removed the data of this participant from the accompanying Fig. 3. As in Experiment 1, we performed a 2 (illusion: hoops-in and hoops-out) × 2 (task: verbal and motor) mixed-design ANOVA. Mauchly's test of sphericity revealed no violations of the sphericity assumption. Levene's test showed that the variances in the hoops-out condition were equal across groups ($p > .12$); for the hoops-in condition, the variances across groups were not equal ($p = .002$).[3]

Results and discussion

The ANOVA revealed no significant main effect of illusion, $F(1, 27) = 0.047$, $p = .830$, $\eta_p^2 = .002$, and no main effect of task, $F(1, 27) = .085$, $p = .773$, $\eta_p^2 = .003$. The interaction between illusion effect and task was also not significant, $F(1, 27) = 4.068$, $p = .054$, $\eta_p^2 = .131$ (see Fig. 3).

Unlike Experiment 1, and contrary to our predictions, the two-tailed illusion failed to induce a systematic illusory bias, both for the beanbag throwing and (more surprisingly) for the verbal estimates. As a consequence, the results of Experiment 2 did not allow us to draw firm conclusions regarding the dissociation between vision for perception and vision for action proposed by the two-visual-systems model (Goodale & Milner, 1992). A comparison of Figs. 2 and 3 suggests that participants made large overestimations of distance for the illusion relative to the control configurations

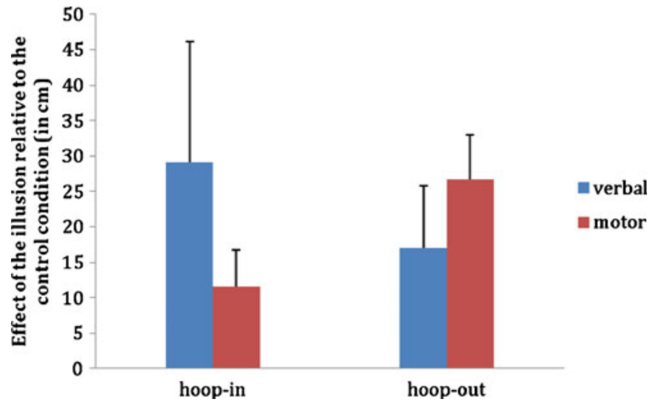

Fig. 3 Mean illusion effects of the hoops-in and hoops-out configurations (adjusted for the mean individual slopes, in centimeters) relative to the control condition (i.e., no hoops) for both tasks (verbal and motor) in Experiment 2. Bars indicate the standard errors of the means

(and also relative to Exp. 3, in which the same distances were used; see Fig. 4 below). We have no explanation for these relatively large errors, but they might have obscured systematic differences (if any) that could have originated from the illusion or the task.

Experiment 3

In Experiment 3, we ran a (modified) replication of Experiment 1. Unlike in Experiment 2, in which the experimental setup was changed on two dimensions (i.e., a two-tailed vs. a one-tailed configuration and positioning of the participants either at a distance of 1.5 m or exactly at the beginning of the shaft), in Experiment 3 we only altered the location at which participants stood, but kept the one-tailed configurations of Experiment 1 unchanged. Despite this, Experiment 3 was motivated by largely the same reasons as Experiment 2: That is, we again attempted to enhance the

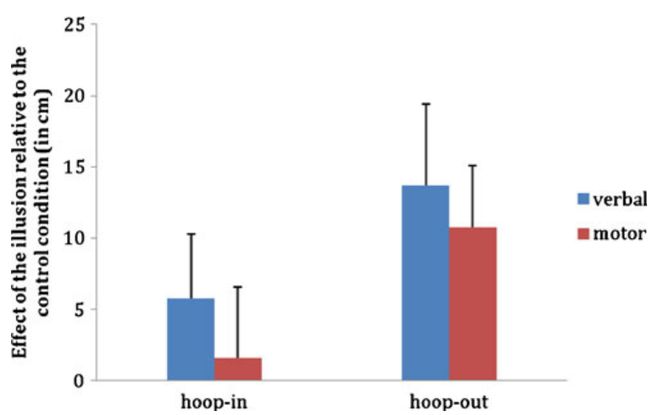

Fig. 4 Mean illusion effects of the hoop-in and hoop-out configurations (adjusted for the mean individual slopes, in centimeters) relative to the control condition (i.e., no hoop) for both tasks (verbal and motor) in Experiment 3. Bars indicate the standard errors of the means

[3] Even though the variances of the hoops-in illusion effect were not homogeneous across groups, we decided to run and report the ANOVA. First, nonparametric tests such as the Kruskal–Wallis test also assume homoscedasticity, and therefore do not provide an alternative. Second, to confirm that the violation of the equality-of-variances assumption did not have a tremendous effect on the outcome, and thus on the interpretation of the data, we additionally performed an independent-samples t test for the hoops-in condition. If equal variances were assumed, the results of the t test would have been $t(28) = 1.028$, $p = .313$. Yet, as indicated by Levene's test, the equality of variances was violated, and therefore a Welch's t test, which does not assume homoscedasticity, was performed: $t(16.217) = 1.028$, $p = .319$. Because the results were highly similar, independent of whether or not homoscedasticity was assumed, we felt on safe ground with the ANOVA. Also note that, in the hoops-out condition, the variances were homogeneous across groups.

relative availability of the allocentric illusion-inducing information. To this end, the participants stood 1.5 m from the base of the shaft of a one-tailed Müller-Lyer illusion, thereby adding an exocentric component to the tasks relative to Experiment 1. Again, we expected that if the greater availability of allocentric information enhances its use, this would lead to large illusory biases in both the perception task and the action task, resulting in a less pronounced dissociation between perception and action than in Experiment 1.

Method

Participants A group of 30 participants (M = 22.3 years, SD = 2.9; 14 male and 16 female) who had not taken part in Experiment 1 or Experiment 2 volunteered to participate in Experiment 3. These participants provided informed consent and were free to withdraw from testing at any time. The experiment was conducted in accordance with the ethical guidelines of the local institution.

Apparatus and stimulus The materials were the same as in Experiment 1.

Procedure The procedure was identical to that of Experiment 1, with one exception. In contrast to Experiment 1 and identical to Experiment 2, participants stood at a distance of 1.5 m from the beginning of the ribbon line (i.e., the endpoint of the shaft closest to them) when either providing verbal estimates or throwing the beanbag to the endpoint location of the shaft farthest from them.

Data analysis The data analysis was identical to that of Experiments 1 and 2. In Experiment 3, for one participant the response to the hoop-in illusion in the verbal estimate task was identified as an outlier (more than 3 SDs above the mean), and consequently was removed from further analyses. Note that we also removed the data of this participant from the accompanying Fig. 4. As in Experiments 1 and 2, we performed a 2 (illusion: hoop-in and hoop-out) × 2 (task: verbal and motor) mixed-design ANOVA. Mauchly's test of sphericity revealed no violations of the sphericity assumption, and Levene's test showed that the variances were equal across groups and illusion (both ps > .37).

Results and discussion

The ANOVA revealed a significant main effect of illusion, $F(1, 27) = 6.001$, $p = .021$, $\eta_p^2 = .182$, indicating that the hoop-out illusion led to significantly larger overestimations (12.19 cm) than did the hoop-in illusion (3.63 cm). We observed neither a significant main effect of task, $F(1, 27) = 0.357$, $p = .555$, $\eta_p^2 = .013$, nor a significant interaction between illusion and task, $F(1, 27) = 0.035$, $p = .853$, $\eta_p^2 = .001$ (see Fig. 4).

Consistent with Experiment 1, the results revealed the predicted illusion effect; that is, distance was overestimated for the hoop-out relative to the hoop-in illusion. However, in contrast to Experiment 1, we found no significant interaction between illusion effect and task, indicating that when participants stood at a distance of 1.5 m from the beginning of the ribbon line (Exp. 3) of the one-tailed illusion, the illusion effect did not differ between the verbal and motor tasks (see Fig. 4). Consequently, the dissociation between vision for perception and vision for action observed in Experiment 1 had disappeared.

Importantly, the setups of Experiments 1 and 3 only differed in one respect: the position of the participant. Whereas in Experiment 1 participants stood at the beginning of the shaft of the illusion, in Experiment 3 they stood at a distance of 1.5 m from the beginning of the shaft. Consequently, whereas in Experiment 1 the tasks were entirely egocentric, in Experiment 3 they could be performed either using only egocentric information (i.e., information specifying the distance between the participant and the target at the end of the shaft) or by complementing an egocentric distance component (i.e., information specifying the distance between the participant and the base of the shaft of the Müller-Lyer figure) with an exocentric component (i.e., the target position relative to the base of illusion configuration). The latter approach would increase the availability of allocentric relative to egocentric sources of information. The results showed that the addition of an exocentric distance component was associated with the disappearance of the dissociation between vision for perception and vision for action. Hence, the dissociation may be a function of the relative availability and use of allocentric and egocentric information. Accordingly, when participants act on objects in purely egocentric distance tasks, egocentric information is a potent source of information for absolute distances; hence, because egocentric information is pertinent for action, it results in the commonly observed dissociation with perceptual estimates (see, e.g., Aglioti et al., 1995; Haffenden & Goodale, 1998). However, when task constraints are altered such that egocentric information sources are complemented by allocentric sources of information (i.e., related to exocentric distance), the control of action may increasingly come to rely on allocentric information, inducing illusory biases in both perception and action.

An issue of concern in examining dissociations between vision for perception and vision for action relates to the role and potential use of online feedback (Stöttinger & Perner, 2009). It may be argued that in our experimental tasks, participants did not receive feedback about their performance in the perception task, whereas they did have online visual feedback in the action task (e.g., they saw where the beanbag landed relative to the target). However, because the results of Experiment 3 revealed that the illusion had an impact on both the perception and action tasks, we deem it unlikely that the difference in feedback played a critical role here. However, to rule out the potential impact of different feedback, future experiments should make sure to match the amounts of feedback between different (i.e., perception and action) tasks (Stöttinger & Perner, 2009).

General discussion and conclusion

In three experiments, we examined the roles of vision for perception and action using large-scale Müller-Lyer illusions (with hoops). Participants either threw a beanbag to the end location of the corresponding shaft (i.e., action task) or provided a verbal estimate of the egocentric distance to that location (i.e., perception task). When participants stood at the beginning of the shaft and faced a one-tailed Müller-Lyer illusion in Experiment 1, the results showed an effect of the illusion on the perception task, but no effect on the action task. This dissociation is in accordance with the idea that the visual system comprises two neuroanatomically and functionally separate systems: The ventral stream exploits allocentric information for perception, and the dorsal stream relies on egocentric information to control action (Goodale & Milner, 1992; Milner & Goodale, 1995).

In contrast to Experiment 1, in Experiments 2 and 3—that is, when participants stood at a distance of 1.5 m from the beginning of the shaft and faced, respectively, two-tailed and one-tailed configurations of the Müller-Lyer illusion—the results revealed no dissociation between perception and action. In Experiment 2, the predicted illusion effects were not found, not even in the perception task. We have no explanation for this failure. However, in contrast to Experiment 1, Experiment 3 did show the illusion effect in both the perception and action tasks. Notably, Experiments 1 and 3 differed only with respect to the positioning of the participant relative to the Müller-Lyer configuration. That is, participants stood at the base of the shaft of the illusion in Experiment 1, whereas in Experiment 3 they stood at a distance of 1.5 m from the base of the shaft. Put differently, whereas the tasks in Experiment 1 were egocentric, in Experiment 3 the tasks contained an egocentric as well as an exocentric distance component. This manipulation allowed the participants to use additional allocentric information that related to the relative distance between the beginning and end points of the shaft.

In contrast to the predictions from the two-visual-systems model (Milner & Goodale, 1995, 2008), this increase in the availability of allocentric relative to egocentric information resulted in both perception and action being affected by the illusion. Hence, it seems that participants used all of the available sources of distance information that were relevant for solving the task at hand (be that task perception estimation or an action task). This is not an unreasonable suggestion if one contends that, for biological systems, it is adaptive to act opportunistically. Following this line of reasoning, the results seem to suggest that the distinction between vision for perception and vision for action is not uniquely a functional separation between perception and action tasks, as was originally proposed by Milner and Goodale (1995, 2008), but that it also depends on the propensities to use egocentric and allocentric information. That is, the functional distinction is critical, but not absolute, because it is granted by the relative availability of egocentric or allocentric information.

To conclude, our experiments indicate that visual illusions not only influence perceptual estimates, but can also influence target-directed actions if egocentric information is a less potent source of information. This can be the case when an egocentric distance task is complemented by a task-relevant exocentric distance component that enhances the availability of allocentric relative to egocentric information sources, in perception as well as action. However, if a task is uniquely egocentric, as Milner and Goodale (1995, 2008) surmised, then egocentric information is more potent, in particular for controlling action. Consequently, the effect of an illusion will be small or negligible (see also Wraga et al., 2000). If these conjectures are correct, the dorsal and ventral streams would first and foremost be dedicated to the use of egocentric and allocentric information, respectively. Although this may often map onto dissociations between action and perception, this need not be the case (see also de Wit, van der Kamp, & Masters, 2012).

References

Aglioti, S., DeSouza, J. F. X., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology, 5,* 679–685.

Bruno, N. (2001). When does action resist visual illusions? *Trends in Cognitive Sciences, 5,* 379–382.

Bruno, N., Bernardis, P., & Gentilucci, M. (2008). Visually guided pointing, the Müller-Lyer illusion, and the functional interpretation of the dorsal–ventral split: Conclusions from 33 independent studies. *Neuroscience and Biobehavioral Reviews, 32,* 423–437. doi:10.1016/j.neubiorev.2007.08.006

Bruno, N., & Franz, V. H. (2009). When is grasping affected by the Müller-Lyer illusion? A quantitative review. *Neuropsychologia, 47,* 1421–1433. doi:10.1016/j.neuropsychologia.2008.10.031

Bruno, N., Knox, P. C., & de Grave, D. D. J. (2010). A meta-analysis of the effect of the Müller-Lyer illusion on saccadic eye movements: No general support for a dissociation of perception and oculomotor action. *Vision Research, 50,* 2671–2682. doi:10.1016/j.visres.2010.09.016

Caljouw, S. R., van der Kamp, J., & Savelsbergh, G. J. P. (2010). Visual illusions and the control of ball placement in goal-directed hitting. *Research Quarterly for Exercise and Sport, 81,* 410–415.

de Wit, M. M., van der Kamp, J., & Masters, R. S. W. (2012). Distinct task-independent visual thresholds for egocentric and allocentric information pick up. *Consciousness and Cognition, 21,* 1410–1418.

Franz, V. H., Fahle, M., Bülthoff, H. H., & Gegenfurtner, K. R. (2001). Effects of visual illusions on grasping. *Journal of Experimental Psychology. Human Perception and Performance, 27,* 1124–1144. doi:10.1037/0096-1523.27.5.1124

Gibson, J. J. (1986). *The ecological approach to visual perception*. Boston, MA: Houghton-Mifflin. Original work published in 1979.

Glover, S. (2004). Separate visual representations in the planning and control of action. *The Behavioral and Brain Sciences, 27,* 3–24.

Glover, S., & Dixon, P. (2004). Likelihood ratios: A simple and flexible statistic for empirical psychologists. *Psychonomic Bulletin & Review, 11,* 791–806. doi:10.3758/BF03196706

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15,* 20–25. doi:10.1016/0166-2236(92)90344-8

Haffenden, A. M., & Goodale, M. A. (1998). The effect of pictorial illusion on prehension and perception. *Journal of Cognitive Neuroscience, 10,* 122–136.

Loomis, J. M., da Silva, J. A., Fujita, N., & Fukusima, S. S. (1992). Visual space perception and visually directed action. *Journal of Experimental Psychology. Human Perception and Performance, 18,* 906–921. doi:10.1037/0096-1523.18.4.906

Loomis, J. M., da Silva, J. A., Philbeck, J. W., & Fukusima, S. S. (1996). Visual perception of location and distance. *Current Directions in Psychological Science, 5,* 72–77.

Michaels, C. F. (2000). Information, perception and action: What should ecological psychologists learn from Milner and Goodale (1995)? *Ecological Psychology, 12,* 241–258.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford, UK: Oxford University Press.

Milner, A. D., & Goodale, M. A. (2008). Two visual systems re-viewed. *Neuropsychologia, 54,* 774–785. doi:10.1016/j.neuropsychologia.2007.10.005

Schenk, T. (2006). An allocentric rather than perceptual deficit in patient D.F. *Nature Neuroscience, 9,* 1369–1370.

Stöttinger, E., & Perner, J. (2006). Dissociating size representation for action and for conscious judgment: Grasping visual illusions without apparent obstacles. *Consciousness and Cognition, 15,* 269–284.

Stöttinger, E., & Perner, J. (2009). Consistency in exchange for inappropriately matched visual feedback? Comment on Franz and Gegenfurtner (2008) "Grasping visual illusions: Consistent data and no dissociation. *Cognitive Neuropsychology, 26,* 412–417. doi:10.1080/02643290903135750

van der Kamp, J., van Doorn, H., & Masters, R. S. W. (2009). A Judd illusion in far-aiming: Evidence of a contribution to action by vision for perception. *Experimental Brain Research, 197,* 199–204.

Welch, R. B., Post, R. B., Lum, W., & Prinzmetal, W. (2004). The relationship between perceived length and egocentric location in Müller-Lyer figures with one versus two chevrons. *Perception & Psychophysics, 66,* 1095–1104.

Wraga, M., Creem, S. H., & Proffitt, D. R. (2000). Perception–action dissociations of a walkable Müller-Lyer configuration. *Psychological Science, 11,* 239–243. doi:10.1111/1467-9280.00248