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Are the original Roelofs effect and the induced Roelofs effect caused by the same shift in straight ahead?

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Abstract

We investigated whether the original Roelofs effect and the induced Roelofs effect are caused by the same shift in perceived straight ahead. Subjects were presented with a target within a frame in complete darkness. Target and frame could both be shifted to the left or right of objective straight ahead. On separate trials, subjects gave verbal estimates about the position of either the target or the frame. The eccentricity of the frame was underestimated (the original Roelofs effect). However, the perceived position of the target did not follow this misjudgement of the eccentricity of the frame (the induced Roelofs effect was not present). Thus, it is unlikely that both effects have a common origin in misjudging egocentric straight ahead.
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1. Introduction

Many studies have examined whether there is a difference between how susceptible perception and action are to visual illusions (reviewed by Carey (2001)). Often, visual illusions cause biases in perceptual tasks, but do not influence goal directed motor output. One example of a dissociation between perceptual and motor tasks was reported by Bridgeman, Kirch, and Sperling (1981), who showed that induced motion (apparent motion of a target when the background moves) affected pointing less than it did perceptual judgements. The perceptual judgement was whether the target had moved. In the motor task, subjects had to point to the final target position.

Smeets and Brenner (1995) noted that motion (or displacement) and position were confounded in the above-mentioned study. They demonstrated that motion of the background led their subjects to misjudge the movement of the target but that it did not have an effect on their judgement of position. Therefore, they argued that the results of Bridgeman et al. were not an indication for a dissociation between perception and action, but for one between position and motion (or displacement). A similar dissociation between position and size could account for the apparent absence of an influence of illusions on grasping (Brenner & Smeets, 1996; Smeets & Brenner, 2001).

Bridgeman, Peery, and Anand (1997), Bridgeman and Huemer (1998) and Bridgeman, Gemmer, Forsman, and Huemer (2000) also found a dissociation between perception and action in experiments that do not involve motion or size. They induced a bias in a target's apparent position by placing a frame around the target. An offset of the frame to one side of the subject's objective median plane caused a bias in the perceived target position in the opposite direction (the induced Roelofs effect). Goal directed arm movements towards that target remained accurate despite the perceptual mislocalization. Their interpretation is that the results are caused by a dissociation between perception and action. These results cannot easily be explained by the arguments of Smeets and Brenner (1995, 2001).

In order to investigate whether it is possible to explain Bridgeman's findings without assuming that there are two visual systems, we would like to know what causes the induced Roelofs effect. To do so, we first turned to the original Roelofs effect. Roelofs (1935) showed that if a rectangular frame is presented with one of its edges on the subject's objective median plane, that

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edge seems to be shifted to the side opposite to the rest of the frame. Werner, Wapner, and Bruell (1953) showed that the original Roelofs effect was not only present when one edge of the frame was on the objective median plane, but also with a more subtle shift of the frame. They presented a single luminescent frame in a darkened room. The frame was shifted a little to the right or to the left of the objective median plane. The subject's task was to fixate the center of the frame and indicate the position in space that appeared straight-ahead. Werner et al. (1953) found systematic shifts of the position of the apparent straight ahead in the direction of the center of the frame.

In the present experiment we investigate whether the original Roelofs effect and the induced Roelofs effect could be caused by a shift in perceived straight ahead (Fig. 1). If so, it would be all the more surprising that such a shift does not influence action because an illusory shift in perceived egocentric location is one of the most likely kinds of illusions to influence action (Smeets & Brenner, 2001; Rossetti, 1998).

If the original and induced Roelofs effects are both caused by a shift in perceived straight ahead we can make two predictions. The first prediction concerns the induced Roelofs effect. If the frame modifies the judgement of what is straight ahead, we expect the order of presentation to make a difference. In the present experiment three orders of presentation are used: target shown before frame, both shown simultaneously or frame shown before target. When the target is presented first, we expect target position (relative to straight ahead) to have been determined before the frame shifted the "straight ahead", so no induced Roelofs effect is expected. When the target and the frame are presented simultaneously, we expect to find an induced Roelofs effect. When the frame is presented first the effect of the frame on the straight ahead might still be present, so we expect to find an induced Roelofs effect. These predictions were tested in a first set of trials ("single task"), in which subjects had to estimate the target position.

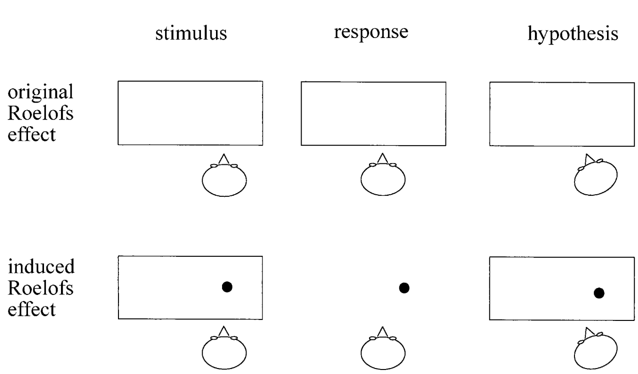

Fig. 1. A hypothetical explanation for both the original and induced Roelofs effect. When a frame is shifted to the left, it's eccentricity is underestimated; i.e. it is judged too far to the right (original Roelofs effect). The hypothesis is that the perceived straight ahead (indicated by the head orientation) shifts to the left, in the direction of the frame. The same hypothesis can explain why the judged position of the target also shifts to the right (induced Roelofs effect).

The second prediction concerns the relation between the induced and the original Roelofs effect. If a shift in the judged straight ahead underlies both effects, the magnitude of the original and of the induced Roelofs effect should be the same. We tested this hypothesis directly with a second set of trials ("dual task"), in which subjects had to estimate both the position of the target and of the frame. Here too we varied the order of presentation.

2. Method

2.1. Subjects

Six subjects participated in the single task and six other subjects in the dual task. All had normal or corrected-to-normal vision and were naïve with regard to the purpose of this study.

2.2. Apparatus and stimulus

The experiments were conducted in a dark room. A chin-rest was placed 50 cm from a computer screen (39.2×29.3 cm, 815×611 pixels, 120 Hz) to help subjects keep their head directed at the midpoint of the screen. All measures are given in centimeters relative to this midpoint. At this distance, 1 cm corresponded to 1.15°. To prevent the subject from seeing any reflections from the screen, subjects looked into a "box" made of black curtains, and a red filter was placed in front of the computer screen.

The stimulus on the screen consisted of a small red target disk and/or a large red rectangular frame. Both were presented at eye height, at various horizontal positions. The diameter of the target disk was 0.75 cm. The frame width was 18.3 cm. It's height was 7.4 cm. Line-width of the frame was 0.3 cm.

2.3. Procedure

2.3.1. Single task

The experiment started with a training phase. During this phase only the target was shown. On each trial of the training phase, subjects had to verbally estimate the target's position relative to straight ahead (in centimeters). Feedback about the real target position (in centimeters) was then shown as a number on the screen. The range of target positions was from 5 cm to the left of the subject's objective median plane to 5 cm to the right, in steps of 0.5 cm. Leftward offsets were considered negative. Thus, if the subject thought that the target was 3 cm to the left of straight ahead, he would answer −3. The training lasted at least 10 min. After this, the training ended when five consecutive trials were considered correct.

Before participants started the test phase, they were told that no more feedback would be given. Both the target and the frame were presented in each trial of the test phase. The target could be presented at five positions: either straight ahead, or 3 or 1.5 cm to the left or right of the objective midline. The frame could also be presented at five different positions either straight ahead, or 5 or 2.5 cm to either side of the objective midline. The target and frame were each visible for 500 ms and could be shown in three ways. In the *simultaneous* condition both were presented together for 500 ms. In the *target first* condition the target was presented for 500 ms, followed by a 100 ms dark interval and then the frame for 500 ms. For the *frame first* condition, the order of presentation was reversed. Again, subjects had to verbally estimate the position of the target (in centimeters) relative to straight-ahead. Each of the five frame positions was combined with each of the five target positions in every order of presentation, and each combination of positions was shown once. This gives a total of 75 trials: 5 frame positions, 5 target positions, 3 orders of presentation.

In order not to give the subjects any spatial reference when giving the response, the experimenter registered the verbal responses on a keyboard. The subject could not see this person (or anything else in the room). Total duration of the experimental session was about half an hour.

2.3.2. Dual task

The training phase of this task was similar to that of the single task, except that either the target or the frame was shown on each trial. The subject had to judge the position of the presented object (target or frame). Subjects never saw both target and frame on a single trial of the training phase. The order in which they were presented was random. The minimum duration of the training was 15 min.

The stimuli in the test phase of the dual task were exactly the same as in the test phase of the single task. Subjects had to estimate the position of either the target or the frame. They did not know which position they had to estimate when they saw the stimulus. If a short sound was presented 500 ms after the stimulus the estimate was for the frame. Otherwise, it was for the target.

Every frame–target combination was presented twice: once to estimate the target position and once to estimate the frame position. This gives a total of 150 trials: 5 frame positions, 5 target positions, 3 orders of presentation, 2 estimates. All trials were presented in a random order. Total duration of the experimental session was about 45 min.

2.4. Statistical analysis

In order to quantify the influence of frame position on the subjects' judgements, we fit a linear model to the data. Bridgeman et al. (1997, 2000) have shown that the relationship between the target's position and the subjects' judgements of that position is linear. We assume that the same is true for the relationship between the frame's position and the subjects' judgements of the target's position, and that the effects of frame position and target position are independent. We can therefore perform a multiple regression to determine how the position of the target and of the frame influence the perceptual judgements of the target's position. This was done separately for every subject. A similar analysis was conducted for the judgement of the frame's position. These analyses were performed for each order of presentation. The regression coefficients (the frame and target gains) show how much the response depends on a change in the independent variables (frame position and target position). A gain of 1 means that the change in response is equal to the change in the independent variable. A gain of 0 means that the response does not depend on the independent variable.

Statistical tests were all conducted across subjects. One-sample *t*-tests were performed to check whether the gains differed from 0 or 1 (to check whether there is any effect). If the frame gain of the estimate of the target's position is significantly smaller than 0, there is an induced Roelofs effect. If the frame gain of the estimate of the frame's position is smaller than 1, i.e. if subjects underestimate the eccentricity of the frame, there is an original Roelofs effect. We are primarily interested in the effect of the frame (frame gains), but we also examined whether subjects underestimated the eccentricity of the targets (target gain <1). A one way repeated measures ANOVA was performed on the frame gains to see whether the order of presentation (frame first, simultaneous, target first) made a difference.

3. Results

3.1. Single task

Fig. 2 shows the average perceived target position of the six subjects for every frame and target position when target and frame were presented simultaneously. Furthermore, it shows how the linear model fitted to the data (described in the statistical analysis section). In this figure the slope of the surface along the frame position axis corresponds with the frame gain. The slope along the target position axis corresponds with the target gain. From this figure it is clear that both target and frame position influence the judgements of target position, but a quantitative reading is impossible.

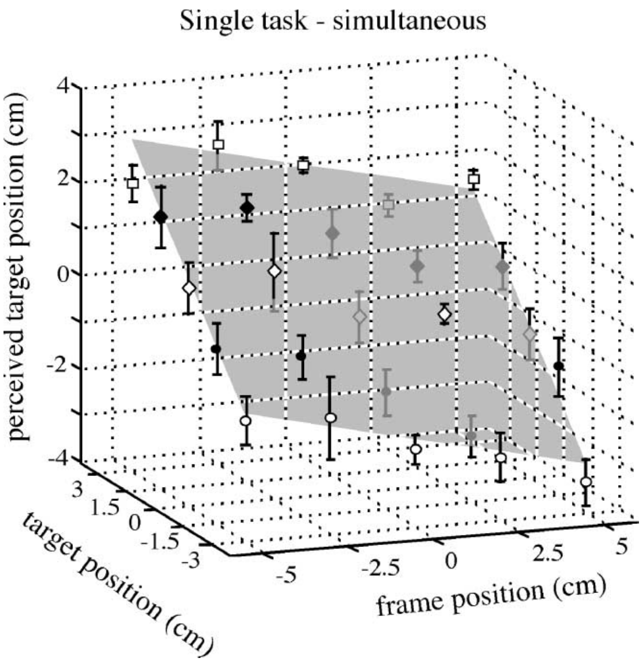

Fig. 2. Mean perceived target positions for simultaneous presentation in the single task. Error bars represent standard errors between subjects' means. The surface shows the outcome of a multiple regression for the independent variables target position and frame position. Grey data points indicate a position behind the surface. Symbols indicate the target position: (○) −3.0, (●) −1.5, (◇) 0.0, (◆) 1.5, (□) 3.0.

In order to be able to read the data in a quantitative fashion, we plot the data further in 2D graphs like Fig. 3. In these graphs target position is represented by different symbols instead of by a third axis. The regression surface is represented by (parallel) lines that are the intersections between the regression surface and five separate planes for the five target distances. The slope of these lines corresponds with the frame gain. The separation between the lines corresponds with the target gain. Fig. 3 shows the average perceived target position of the six subjects for every frame and target position for all three conditions. Fig. 3B shows the same data and regression as Fig. 2. The slope of the lines (the induced Roelofs effect) depends on the order of presentation. The ANOVA for the frame gains showed a significant difference between the orders of presentation ($F(2) = 5.49$, $P < 0.05$).

The leftmost column of Table 1 shows the mean target and frame gains with their standard errors. As expected, we found an induced Roelofs effect in the simultaneous condition (see Table 1). We found no induced Roelofs effect when the target was presented first. Presumably, the frame position was ignored because subjects judged the target's position before the frame was presented. There was also no significant induced Roelofs effect when the frame was presented first. In all cases the eccentricity of the target was underestimated (target gains significantly smaller than one).

3.2. Dual task

We present the results of the estimates of frame position (Fig. 4) as frame errors rather than perceived frame positions. The frame error is the judged frame position minus the actual frame position. The regression lines within each figure are almost exactly superimposed and the lines are very similar in the three graphs, indicating that the timing and position of the target was irrelevant. The slopes of the regression lines show that frame error depends on the frame position. The mean frame gains are less than one (about 0.6, fourth column of Table 1), indicating that the eccentricity of the frame is underestimated. This is the original Roelofs effect. The Roelofs effect in this task is larger than the induced Roelofs effect in the single task (steeper slopes in Fig. 4 than in Fig. 3; note the different scales).

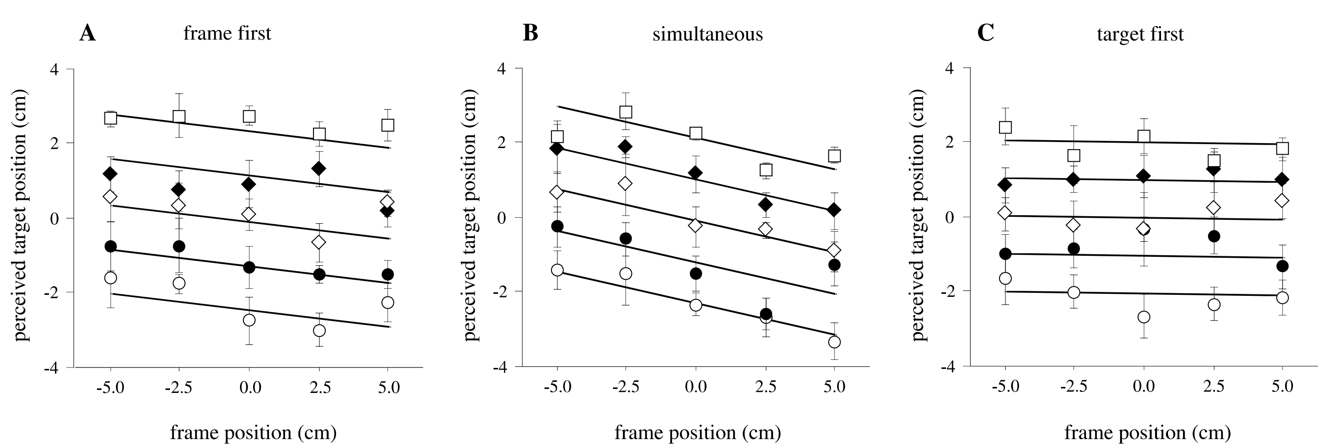

Fig. 3. Mean perceived target positions for the single task. Symbols indicate the target position: (○) −3.0, (●) −1.5, (◇) 0.0, (◆) 1.5, (□) 3.0. Error bars represent standard errors between subjects' means. The lines show the outcome of a multiple regression for the independent variables target position and frame position. (A) Frame is presented first, (B) simultaneous presentation, (C) target is presented first. Part B shows the same data and regression as Fig. 2.

Table 1
Mean regression coefficients (with between-subjects standard errors) from the multiple regression

	Single task target estimation		Dual task frame estimation		Dual task target estimation	
	Target gain[a]	Frame gain[b]	Target gain[b]	Frame gain[a]	Target gain[a]	Frame gain[b,c]
Frame first	0.78^{**} (0.04)	−0.07 (0.03)	−0.03 (0.02)	0.63^{**} (0.04)	0.76 (0.12)	$0.07^{\S\S}$ (0.03)
Simultaneous	0.73^{**} (0.05)	$-0.17^{\#}$ (0.05)	−0.03 (0.03)	0.59^{**} (0.04)	0.62^{**} (0.05)	$0.04^{\S\S}$ (0.03)
Target first	0.67^{**} (0.05)	−0.01 (0.01)	0.03 (0.04)	0.59^{**} (0.03)	0.72^{**} (0.06)	$0.06^{\S}$ (0.03)

[a] t-test: 1. Compared with gain = 1 ($^{*}p < 0.05$; $^{**}p < 0.01$).
[b] t-test: 2. Compared with gain = 0 ($^{\#}p < 0.05$; $^{\#\#}p < 0.01$).
[c] t-test: 3. Compared with equivalent condition of single task ($^{\S}p < 0.05$; $^{\S\S}p < 0.01$).

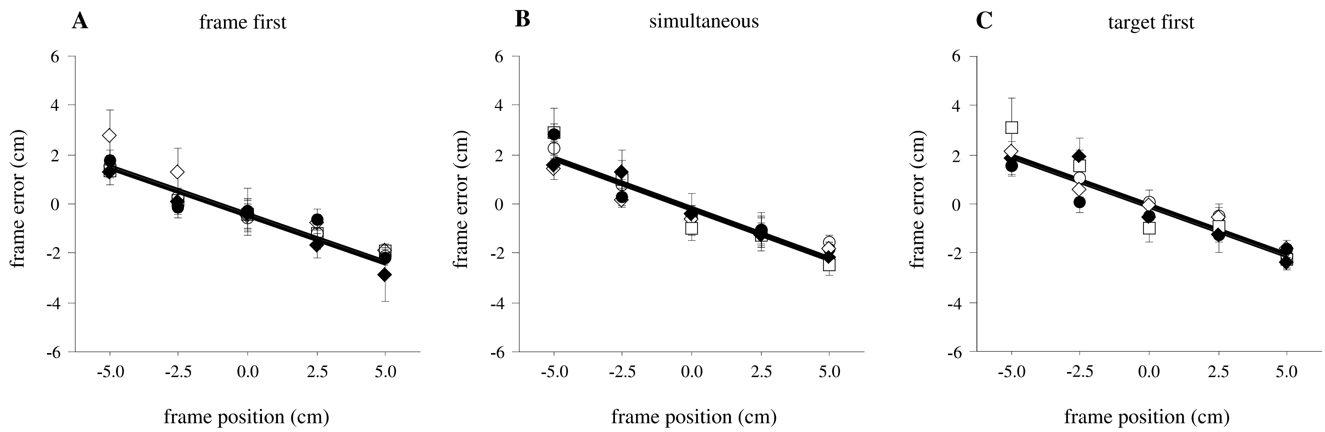

Fig. 4. Mean frame errors (perceived frame position—actual frame position) in the dual task. The symbols indicate the different target positions: (○) −3.0, (●) −1.5, (◇) 0.0, (◆) 1.5, (□) 3.0. Error bars represent standard errors between subjects' means. The slope of the lines with frame position shows the deviation from a frame gain of one. (A) Frame is presented first, (B) simultaneous presentation, (C) target is presented first.

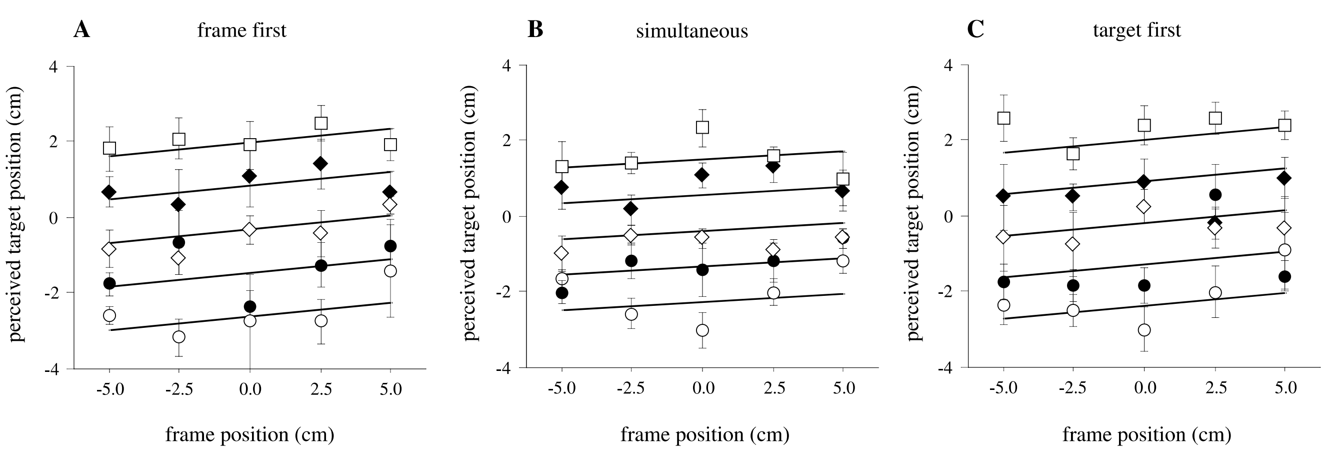

Fig. 5. Mean perceived target positions for the dual task. The symbols indicate the target positions: (○) −3.0, (●) −1.5, (◇) 0.0, (◆) 1.5, (□) 3.0. Error bars represent standard errors between subjects' means. The lines show the outcome of a multiple regression for the independent variables target position and frame position. (A) Frame is presented first, (B) simultaneous presentation, (C) target is presented first.

Fig. 5 shows the mean responses in the dual task (six subjects) when the target's position had to be estimated. The slope of the regression lines corresponds with the frame gain, and the distance between the lines corresponds with the target gain (as in Fig. 3). No induced Roelofs effect (negative slope) was found for any order of presentation. Instead, a tendency for an inverse effect was found. As the original Roelofs effect was present in this task, this means that the original and the induced Roelofs effect cannot be caused by the same shift in perceived straight ahead.

The frame gains for estimates of the position of the target in the dual task (Table 1, final column) are significantly different from the corresponding frame gains in the single task (Table 1 second column). Thus subjects responded differently to the exact same question for the same stimuli in the two tasks.

4. Discussion and conclusion

To obtain one value for the induced Roelofs effect, we fitted a linear model to our data. Although the linear model seems to fit reasonably well, it is certainly not a perfect fit to all the data. We nevertheless did not attempt to find a model that gives a better fit because the linear model gives values that can be interpreted directly in terms of the hypothesis that we were testing. Moreover, it is evident that a model that gives a better fit to the data would not change the conclusion that the original and the induced Roelofs effect cannot be caused by the same shift in perceived straight ahead.

The results of the simultaneous condition in the single task showed the same illusory effect as in the experiment of Bridgeman et al. (1997): a shift in the frame caused a bias in target position in the opposite direction to the offset of the frame (an induced Roelofs effect). The frame gain in this condition (0.17) was similar to that in Bridgeman et al.'s comparable studies (0.15 and 0.27 in the 1997 and 2000 papers). Target gain was slightly larger in our study (0.73 rather than about 0.6). We also reproduced the original Roelofs effect in the frame estimation trials of the dual task. When the frame was not straight ahead its eccentricity was underestimated, consistent with the findings of Roelofs (1935) and Werner et al. (1953). This result was totally independent of the timing and location of the target. Thus, we could replicate the results of the studies that were the basis of our hypothesis that misestimation of straight ahead is the common source of the original and induced Roelofs effect.

If egocentric straight ahead is misestimated, the extent of the mislocalization of target and frame should be the same. In the dual task, the original and induced Roelofs effects were not equal. The target did not even shift in the same direction as the frame. A common origin of both effects in misjudging egocentric straight ahead is thus very unlikely. The disappearance of the induced Roelofs effect in our dual task has an important additional consequence.

The presence of an induced Roelofs effect in perceptual tasks and the failure of this perceptual illusion to influence action has been interpreted as evidence for separate visual mechanisms for perception and action (Bridgeman et al., 1997, 2000). Perceptual judgements were reported by indicating the target position relative to the subject's midline on a visible ruler (Bridgeman et al., 1997) or by estimating the target position in a 5 alternative forced choice task either verbally (Bridgeman et al., 2000) or by pressing a key on a keyboard (Bridgeman et al., 1997). Despite these differences between the perceptual tasks, there was always an effect of the illusion. Therefore, the absence of the induced Roelofs effect in pointing tasks was regarded as a strong argument for a dissociation between perception and action.

In our experiment we found that the influence of the illusion on perceptual judgements could disappear when a small variation was introduced to the task, although exactly the same stimuli and response method were used. The main difference between the target estimation responses in the single task and the dual task is that subjects are more aware of the fact that the frame could have different positions in the latter case. The frame estimation part of the dual task emphasizes this. Consequently, whereas the frame might be regarded as a useful reference in the single task, it is evident that it is not a reference in the dual task. Therefore the only useful information to judge the target position in the dual task is egocentric information. In pointing or jabbing it is evident from the task itself that egocentric information about target location is more useful than information relative to a frame. The critical difference between the tasks is therefore probably the extent to which allocentric information can be considered useful information, rather than the kind of response (Vishton, Rea, Cutting, & Nunez, 1999). We conclude that the absence of the Roelofs illusion in action should not be considered as evidence for a dissociation between visual processing of spatial information for perception and action.

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