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# The effect of stimulus blanking on the detection of intrasaccadic displacements of translating objects

Veerle Gysen <sup>\*</sup>, Karl Verfaillie, Peter De Graef*Laboratory of Experimental Psychology, University of Leuven, Tiensestraat 102, 3000 Leuven, Belgium*

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## Abstract

In a display with a stationary and a translating object, subjects made a saccade towards one of the objects and had to detect intrasaccadic changes in the position of either the saccade target or the saccade flanker. Sensitivity for displacements of the stationary and moving objects was measured in conditions with (60 and 220 ms) and without blanking. In the conditions without blanking, displacement detection for translating objects was better than detection for stationary objects, which confirmed previous results (*Vis. Res.* 42 (2002) 379). This pattern was reversed in the blanking conditions: Sensitivity for intrasaccadic displacements of the translating object decreased drastically in comparison to conditions without a blank and was even lower than sensitivity for the stationary object. The results suggest differences in the transsaccadic spatial representation of translating and stationary objects. While a change in the spatial position of a stationary object can be detected after a blank period of 60 and 220 ms, this seems impossible for a translating object, indicating timing differences in postsaccadic spatial localization processes. Accounts in terms of a fast and accurate motion processing mechanism that possibly makes use of gain control are discussed.

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*Keywords:* Saccade; Motion; Blanking

## 1. Introduction

For a human observer, only a limited part of the available visual information in the surroundings can be caught by the eyes in a single fixation. Therefore, saccadic eye movements are made to bring new information into the high-acuity foveal region of the retina. During these eye movements, visual perceptual sensitivity is strongly suppressed (Burr, Morrone, & Ross, 1994; Ross, Morrone, Goldberg, & Burr, 2001). Moreover, saccades shift and smear the projection of the world on the retina. This has led to the question of how observers achieve a spatially stable and temporally seamless percept in spite of the constant alternation between fixations and saccades.

Research on transsaccadic integration often capitalizes on the saccadic suppression phenomenon. The

technique involves introducing intrasaccadic changes, i.e., during the observer's eye movement, in certain object or scene attributes such as object-position, -orientation, or -color, (Grimes, 1996; Henderson & Hollingworth, 1999; McConkie & Currie, 1996; Rayner, McConkie, & Zola, 1980; Verfaillie, De Troy, & Van Rensbergen, 1994) and testing the influence of these changes on detection rates, reaction times, and fixation times. Because of saccadic suppression (Burr et al., 1994), the transient changes themselves are not visible. Instead, it is assumed that the visual system must use some kind of memory to support continuous perception across saccades. Investigating the influence of making intrasaccadic changes—so that the presaccadic scene differs from the postsaccadic scene—can shed light on the content of transsaccadic memory.

Experiments on object perception (Pollatsek, Rayner, & Henderson, 1990) and biological-motion perception (Verfaillie et al., 1994) have demonstrated that the exact position of an object or a biological-motion walker is not maintained accurately across saccades. In other words, intrasaccadic position changes of objects are hard to detect; perception continues without the viewer

<sup>\*</sup> Corresponding author. Present address: CNBC, University of Pittsburgh, 115 Mellon Institute, 4400 Fifth Avenue, Pittsburgh, PA 15213-2683, USA. Fax: +1-412-268-5060.

E-mail address: [vgysen@cnbc.cmu.edu](mailto:vgysen@cnbc.cmu.edu) (V. Gysen).

actually noticing that anything was altered intrasaccadically. Hence, it was hypothesized that transsaccadic object representations are relatively independent of object position. Recently, we observed that, in comparison to stationary objects, intrasaccadic displacements of a translating object were detected with higher accuracy (Gysen, De Graef, & Verfaillie, 2002). Specifically, we presented viewers with displays containing one stationary object and one moving object which translated on a horizontal axis towards the stationary object. Subjects were instructed, on a trial-by-trial basis, to make a saccade to either the translating or the stationary object. During the saccade, one of the two objects could change position and the subject indicated which object, if any, had changed. Signal detection sensitivity values ( $d'$ ) were significantly higher for the translating object than for the stationary object.

A possible explanation for these findings is a motion perception system with high temporal and spatial resolution, optimally adapted to keep track of translating objects, even across saccades.<sup>1</sup> We assume that, in order to track objects with high precision, the motion system is in constant need of new 'up to date' information. Under this hypothesis, position information for translating objects is continuously updated to allow precise saccadic targeting, accurate tracking, collision detection, etc. This system could also provide the necessary architecture for bridging saccades: Fast and precise pre- and post-saccadic spatial processing can be a way (and may be a necessary condition) for the motion system to detect and incorporate changes in the path of motion.<sup>2</sup> For stationary objects, position information may be less frequently revised, probably because the visual system assumes that the object will hold its position across fixations (Deubel, Schneider, & Bridgeman, 1996).

There is neurophysiological evidence in support of a fast and precise motion analysis system. Motion processing involves brain regions, such as MT (V5) and MST (Beckers & Zeki, 1995), that seem well suited to support *high temporal accuracy*. Specifically, the time course of activation across the dorsal pathway (spatial relation analysis), and especially in MT and MST (motion areas), shows short response latencies (Schmolesky et al., 1998; Schroeder, Mehta, & Givre, 1998). V5 receives its main input from the magnocellular pathway,

which is characterized by early activation and fast information transfer (Bullier & Nowak, 1995). Furthermore, recently Livingstone, Pack, and Born (2001) reported on the substructure of MT receptive fields in the macaque. They suggest that direction selectivity is generated within subunits of complex-cell receptive fields. They found that direction selective interactions within these subunits were very *precise spatially*. The optimal distance (i.e., distance between two sequentially presented bars in preferred direction) to get directional interactions was even smaller than the average V1 receptive field size.

Additionally, a relevant neurophysiological finding regarding eye movements and moving objects was reported by Schwartz and Lisberger (1994). They investigated gain control in the smooth-pursuit eye movement system and its role in the target selection for pursuit. Monkeys were trained to fixate or track a small target while perturbations were applied to the target. It was observed that a large eye movement response was evoked when the perturbation was applied to a moving target that the monkey was tracking. A small response was evoked when the same perturbation was applied to a stationary target the monkey was fixating. Apparently, different gain control settings are at work for stationary and moving targets. Schwartz and Lisberger also found that, within pursuit conditions, gain control setting differed depending on the velocity and the duration of the pre-perturbation period. The faster and the more extensive the path of motion was before perturbation the higher the gain. On the basis of additional experiments on postsaccadic pursuit and gain control, Lisberger (1998) suggested that the postsaccadic enhancement seems to be part of the causal linkage for selecting targets for pursuit, and that it acts on the basis of the spatial location of the target rather than its direction of motion.

In sum, fast and precise motion processing mechanisms that can make use of gain control could support an accurate and up-to-date transsaccadic coding of the position of a translating object and allow for transsaccadic perception of its path.

If such a fast integrating mechanism does indeed exist, it probably relies heavily on immediate access to presaccadic information just before the saccade and to postsaccadic information just after the saccade. In this article, we focus on the importance of postsaccadic information: Which temporal window of information is needed postsaccadically to successfully keep track of a translating object across a saccade? As in Gysen et al. (2002), we examined transsaccadic perception of moving objects by instructing subjects to detect intrasaccadic displacements of a translating object. In addition, we investigated the importance of immediate access to postsaccadic information by borrowing a technique introduced, into the transsaccadic perception research

<sup>1</sup> It is important to make the distinction between the perceptual system (measured in our experiments by detection rates) and the sensorimotor system (e.g. measured by accurateness of corrective eye movements). When we intrasaccadically displace objects, the sensorimotor system (Bridgeman, Gemmer, Forsman, & Huemer, 2000) follows these displacements frequently with corrective eye movements although people report not having perceived a position change.

<sup>2</sup> The motion perception system may be using 'short term anticipation' to bridge saccades (Verfaillie et al., 1994).

tradition, by Deubel, Schneider, and Bridgeman (1994). In this so-called blanking technique, the object is removed during the saccade and at the beginning of the postsaccadic fixation. If accurate motion processing requires more or less continuous information input to constantly update the position of the moving object, eliminating the motion information for too long at the beginning of the postsaccadic fixation will probably disrupt accurate transsaccadic perception of the exact spatial characteristics of the motion path.

For stationary objects, the immediate postsaccadic presence of the object has been proven to be of minor importance for high detection of intrasaccadic displacements. In fact, the opposite has been reported. Deubel et al. (1996) observed that postsaccadic blanking of the stationary object for 50–300 ms after the saccadic eye movement drastically increased intrasaccadic displacement detection rates in comparison to a condition without blanking. Deubel et al. (1996) proposed a revision mechanism as a possible explanation for the better performance for stationary objects in blanking conditions. They suggested that for stationary objects the visual system normally adheres to the assumption that the world remains stable across saccadic eye movements. Consequently, small position changes are seldom noticed by the observer. In contrast, when the object is absent after the saccade, the assumption of stability is falsified and information that initially was stored only implicitly becomes available to conscious processes, resulting in much more accurate detection of intrasaccadic displacements.

In sum, introducing a postsaccadic blank should decrease detection rates for intrasaccadic displacements in translating objects, whereas detection rates for displacements of the stationary object should increase in comparison to conditions without blanking. We investigated this hypothesis in two experiments. On each trial, one stationary and one moving object were present and subjects had to make a saccade to one of the objects. During the saccade, both objects could be blanked, but only one object could change position. Essentially, this allowed us to examine the effect of blanking for stationary versus translating objects.

## 2. General methods

### 2.1. Subjects

Eight (six women, two men) and an additional eight subjects (five women, three men) participated in Experiment 1 and 2 respectively. They received a 5 Euro payment per session. All subjects were psychology students, had normal or corrected-to-normal vision, and none of them participated in more than one experiment.

### 2.2. Procedure

Each subject participated in four sessions of 192 randomly ordered trials. In two sessions, detection of intrasaccadic position changes was measured in trials without postsaccadic blank. In the two other sessions, sensitivity for displacements was tested in trials in which a postsaccadic blank was introduced. Half the subjects first performed the position change task with blanking, and the other half the position change task without blanking.

Fig. 1 shows the progression of a typical trial with postsaccadic blank. At the beginning of a trial (frame 1 in Fig. 1) a fixation cross was presented. The subject fixated the cross and pressed a button to indicate that he/she was ready to start the trial. Two crosses appeared where the objects would appear (frame 2), while the subject still was fixating the fixation cross. After 250 ms, the objects appeared (frame 3) and one object immediately started moving (velocity =  $2.68^\circ/\text{s}$ ) horizontally towards the other object. The subject still fixated the fixation cross. After 1 s, a tone signaled the subject to make a saccade. Depending on the ear in which the tone signal was given, a saccade was made to the left or to the right object. In half of the trials, the subject had to make a saccade to the translating object, in the other half to the stationary object.

During this saccade, in the conditions with blanking, the blank started and a horizontal position change could take place (frame 4): The translating object shifted (1/3 of the trials), the stationary object shifted (1/3 of the

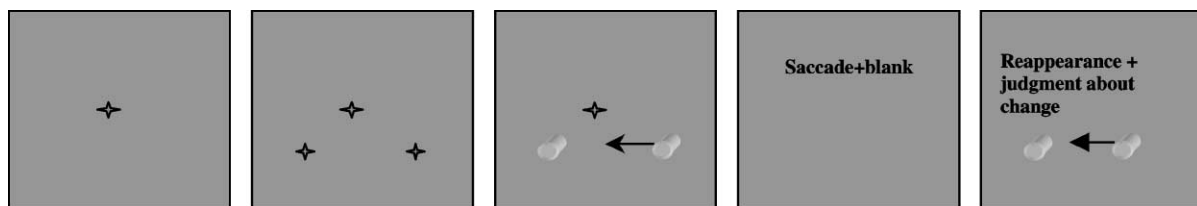


Fig. 1. Sequence of events in a trial. Frame 1: Presentation of fixation cross. Frame 2: Two crosses appear where the objects will be presented. Frame 3: Two objects appear, one stationary and the other translating in the direction of the stationary object. Frame 4: During the saccade, the blank starts and nothing or one of the two objects can change. Frame 5: After the saccade and reappearance of both objects, subjects give an answer.

trials), or nothing changed (1/3 of the trials). Subjects were informed about the three possible types of displacements. The displacement was a  $1^\circ$  shift to the left or to the right of the object's position prior to the initiation of the change.<sup>3</sup> The position change was 12.5% of the distance (at the moment of the saccadic eye movement) between fixation cross and object. During this blank, the position of the moving object was constantly updated, so that it followed its normal path even if the object was not visible. Consequently, after the postsaccadic blank, the object in the no-change trials reappeared in the position that it would occupy if it had continued translating during the blank. After the blank period, the moving object did continue its translation.

In the sessions without blanking, the position change of the moving object was  $0.5^\circ$ . For the stationary object the position change was  $1^\circ$ . The displacement was respectively 6.26% or 12.5% of the distance between fixation cross and object, at the moment of the saccadic eye movement. This is conform with our previous experiments without blanking (Gysen et al., 2002). In the no-blanking conditions, the objects never disappeared from the screen (frame 4, Fig. 1, is not a part of the sequence in the no-blanking trials). The displacement took place during the saccade, the objects remained present and therefore were immediately visible after the eye movement.

After the saccade was made and the objects had reappeared (in case of blanking), the subject had to indicate which object, if any, had changed (frame 5). The subject had a four-button response box and pressed the upper right button with the right index finger when the right object changed and the upper left button with the left index finger when the left object changed. The lower buttons were pressed (with either thumb) when no change was detected. After pressing the buttons, both objects, moving and stationary, disappeared. The message 'New trial' was presented and subsequently the fixation cross for the next trial appeared.

Accuracy and manual reaction time were measured. Reaction time data were used to exclude outliers. Only accuracy data were included in the analysis.

### 2.3. Design

The factorial combination of the type of displacement (translating object, stationary object, or no displace-

ment), the type of saccade target (translating object vs. stationary object), the direction of translation (left–right vs. right–left) produced 12 different conditions, with 32 trials per condition. These conditions were tested in four sessions of 192 randomly ordered trials; two sessions with and two sessions without blanking.

A number of trials were excluded from analysis. First, trials in which the subject did not keep fixating the cross until the tone was presented, were eliminated. Second, trials in which the subject made a saccade to the wrong object also were not considered. The third class of excluded trials consisted of trials where the moving object started to occlude the stationary object before subjects gave a response. Because the subject had to indicate whether the left or right object changed by pressing the left or right button, responses on these trials became ambiguous. Finally, trials with manual reaction times smaller or larger than 2.5 SD below or above the subject's mean were eliminated as outliers. Based on these criteria, 19.7% of the trials were excluded from further analysis in Experiment 1 as well as in Experiment 2.

Response proportions were converted to signal detection values. Hits (i.e., correct identifications of the object that shifted position) were combined with false alarms (i.e., false reports of a displacement of that particular object when nothing was displaced) to derive  $d'$  values (see Appendix A).

Misattributions (i.e., trials in which one of the objects was displaced, but subjects reported that the other object changed position) were analyzed separately.

### 2.4. Apparatus

Stimuli were displayed on a Sony 17" screen with a resolution of  $800 \times 600$  and a 75 Hz refresh rate. The display was viewed binocularly at a distance of 60 cm. Head movements were restricted by a head- and chinrest. Four response keys were connected to a Pentium 233 MHz PC, which controlled stimulus presentation and response registration.

Eye movements were monitored with the Eye Link system (version 2.01 revision, 1999, SensoMotoric Instruments, Teltow, Germany). Only movements of the right eye were tracked. The sampling rate of the Eye Link system is 250 Hz. Every 4 ms the horizontal and vertical gaze position are sampled. Based on this information, the decision about the status of the eye (saccade, blink, fixation) can be made. As soon as a saccade is detected, the computer for stimulus presentation gets this information from the eye monitoring PC within 20 ms after saccade onset and completes a display change within 13.3 ms. Most saccades lasted longer than 45 ms, which gave the computer enough time to perform a display change before the end of the saccade. The blank display appeared on average 14.5 ms before the saccade ended. The blank lasted for 220 ms (Experiment 1) or

<sup>3</sup> A pilot blanking experiment had shown that  $0.5^\circ$  changes of the translating object (as used in Gysen et al., 2002, and in the no-blanking sessions in this article) were very difficult to detect. In this pilot experiment, the average hit rate for  $0.5^\circ$  displacements of the translating object was 14% (the  $d'$  value was 0.17). We decided to use  $1^\circ$  intrasaccadic displacements for the stationary as well as the translating object in the blanking conditions of the experiments presented in this article.

60 ms (Experiment 2), after which the objects reappeared in a changed or unchanged position. In the conditions without blanking, the display change happened on average 14.5 ms before the saccade ended.

### 2.5. Stimulus displays

On each trial, one fixation cross and two objects were present. At the beginning of a trial, the center-to-center distance from the fixation cross to the stationary and moving object was respectively  $8^\circ$  and  $10.1^\circ$ . The distance between the two objects was  $10.7^\circ$ . The moving object was placed at  $7.1^\circ$  and the stationary object at  $3.6^\circ$  from the vertical meridian. One object remained stationary throughout the trial, the other object moved along a linear horizontal trajectory towards the stationary object. Motion was created by horizontally displacing the object one pixel per frame, producing an angular velocity of  $2.68^\circ/\text{s}$ . The direction of motion was randomized across trials. Dependent on which object was moving (left or right object), the horizontal coordinate of the starting position of the objects differed, ensuring that at the time of the saccade, the distance from the fixation cross to both objects was approximately equal ( $8^\circ$ ).

The objects were yellow cones presented on a gray background. Objects subtended  $2^\circ \times 2^\circ$  and appeared in one of two possible depth orientations: a  $-22.5^\circ$  orientation (Fig. 2, left panel) or a  $22.5^\circ$  orientation (Fig. 2, right panel), both rotated around the vertical axis. The fixation cross subtended  $1^\circ \times 1^\circ$ . By combining the two possible object orientations, four starting configurations were possible.

The blank display was created by wiping out the objects for 60 or 220 ms with the same color as the background and then replacing them on the screen.

## 3. Experiment 1

The main purpose of the experiment was to explore the effect of blanking on the detection of intrasaccadic

position changes in a translating versus a stationary object. Subjects participated in four sessions.

Two sessions contained no-blanking trials and replicated our previous research (Gysen et al., 2002). In these conditions, the objects never disappeared from the screen. The stimulus displacement took place during the saccade, on average 14.4 ms before the end of the eye movement.

In two other sessions both objects were blanked for 220 ms. The blank period started during the saccade and continued in the postsaccadic fixation until 220 ms had elapsed. The blank started on average 15.1 ms before the end of the saccade.

### 3.1. Results

$d'$  values were entered in a repeated-measures ANOVA with dynamic status (translating vs. stationary), saccadic status (target vs. flanker), blank presence (blank vs. no blank), and direction of motion (left–right vs. right–left) as within-subject variables and session order as between-subjects variable. Mean sensitivity ( $M$ ) was lower for changes in trials where the translating object moved from right to left ( $M = 1.16$ ) than for changes in trials with the opposite direction of motion ( $M = 1.29$ ),  $F(1, 6) = 12.85$ ,  $p = 0.011$ ,  $\text{MSE} = 0.04$ . Sensitivity was lower for changes in the flanker object ( $M = 0.96$ ) than for changes in the saccade target object ( $M = 1.49$ ),  $F(1, 6) = 11.04$ ,  $p = 0.015$ ,  $\text{MSE} = 0.83$ . Sensitivity was lower for changes in the blank condition ( $M = 0.93$ ) than for changes in the no-blank condition ( $M = 1.51$ ),  $F(1, 6) = 10.28$ ,  $p = 0.018$ ,  $\text{MSE} = 1.06$ . Most importantly, we found a significant interaction between dynamic status and blank presence,  $F(1, 6) = 45.67$ ,  $p = 0.0005$ ,  $\text{MSE} = 0.75$ , (Fig. 3). Sensitivity for displacements of the stationary object was somewhat higher in the presence of a postsaccadic blank. In contrast, sensitivity for displacements of the translating object was much higher without blanking than with blanking.

Misattribution data (11.2% in the blank conditions, 3.63% in no-blank conditions) were analyzed separately. An ANOVA was done on the percentages of



Fig. 2. Stimuli used in Experiments 1 and 2. The left picture is the  $-22.5^\circ$  view, the right picture is the object turned  $22.5^\circ$  around the Z-axis.

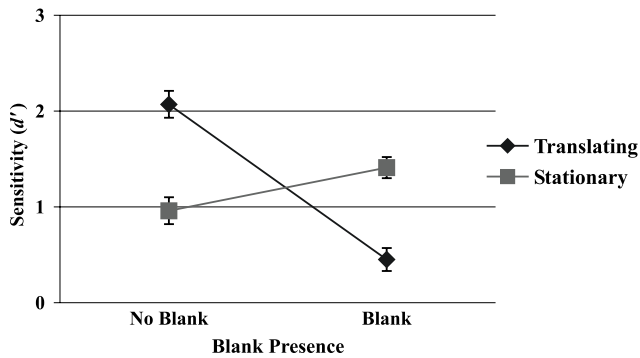


Fig. 3. Sensitivity results ( $d'$ ) from Experiment 1 (means and standard errors) in function of dynamic status of the changed object (translating/stationary) and blank presence (no blank/blank).

misattributions with dynamic status (translating vs. stationary), saccadic status (target vs. flanker), and direction of motion (left–right vs. right–left) as within-subject variables and session order as between-subjects variable. For the blank conditions, the misattributions were higher for changes in the moving object ( $M = 18.28\%$ ) than for changes in the stationary object ( $M = 4.17\%$ ),  $F(1, 6) = 5.67$ ,  $p = 0.054$ ,  $MSE = 0.064$ . None of the other effects involving the within-subject variables were significant.<sup>4</sup>

### 3.2. Discussion

First, the findings of Gysen et al. (2002) are replicated. Without blanking, sensitivity for displacements of the translating object is higher than sensitivity for displacements of the stationary object. Second, blanking improves sensitivity for displacements of the stationary object, while it drastically decreases sensitivity for these changes of the translating object. There may be fundamental differences in the way in which the spatial localization system processes motion and static information across saccades.

For stationary objects, detection rates increase when a postsaccadic blank is introduced. This is in agreement with Deubel et al. (1996). They suggest that possibly transsaccadic coding of object position is quite accurate for stationary objects. Usually, the information is unavailable to conscious perception, because the visual system assumes that the world remains stable. By briefly blanking the saccade target during and just after the saccade, the default assumption of a stable visual world is invalidated and saccade-contingent displacements are easier to detect.

In contrast, for the translating object, our data show that accurate temporal sampling and spatial localization are tightly linked. When the postsaccadic information is taken away for 220 ms, small changes in the translation path are rarely noticed. This supports the hypothesis of a motion system that is constantly updating the spatial information of the translating object. This motion system is probably optimally adapted to relatively fast and prompt interactions, but does not maintain exact information about the path of motion for an extensive amount of time.

Misattributions are more frequent in conditions with blanking than in conditions without blanking. Moreover, in blanking conditions, intrasaccadic displacements of the translating object are frequently misattributed to the stationary object. This could imply that observers show a tendency to use a stable pattern as a frame of reference. One reason could be that a translating object is harder to use as the anchor point of a reference frame (also see Deubel, Bridgeman, & Schneider, 1998). In this scenario, when the translating object is displaced in the blanking condition, subjects sometimes perceive a change in the relative position of the two objects, without being able to decide what object displacement caused the change in relative position. Because postsaccadic blanking has obliterated the basis for transsaccadic position comparison for the moving object, subjects are reluctant to attribute the perceived change to the translating object. Given that blanking has also lifted the default constraint that stationary objects maintain their position across saccades, the change in relative position is therefore ascribed to the stationary object.

In Experiment 1 we did not find an interaction effect between blank presence, dynamic, and saccadic status. This suggests that blanking does not differentially influence sensitivity for target and flanker stationary and translating objects. Sensitivity increases for the stationary target and flanker object while sensitivity decreases for the target and flanker translating object.

## 4. Experiment 2

Experiment 1 demonstrated that a temporal window of at least 220 ms is needed postsaccadically to successfully keep track of a translating object across a saccade. Experiment 2 examines whether that window might be even shorter. Therefore, we replicated Experiment 1, except that the postsaccadic blank only lasted 60 ms. If there is indeed a motion processing mechanism that needs immediate access to postsaccadic information in order to be able to bridge a saccade, then a postsaccadic blank of only 60 ms might be sufficient to dis-

<sup>4</sup> The percentage of misattributions in the no-blank conditions was small (3.63%) and was evenly distributed over stationary and translating objects ( $F < 1$ ).

rupt otherwise accurate transsaccadic memory for the position of a translating object.

For stationary objects, Deubel et al. (1996) already showed that a postsaccadic blank of about 220 ms resulted in a more pronounced increase in accuracy of transsaccadic memory than a shorter blank of 50 ms (albeit that there was still an improvement in comparison to conditions without blanking). We therefore expected that decreasing the blank from 220 to 60 ms would decrease the blanking advantage for stationary objects.

#### 4.1. Results

$d'$  values were entered in a repeated-measures ANOVA with dynamic status (translating vs. stationary), saccadic status (target vs. flanker), blank presence (blank vs. no blank),<sup>5</sup> and direction of motion (left–right vs. right–left) as within-subject variables and session order as between-subjects variable. First, there was a significant effect of saccadic status,  $F(1, 6) = 22.93$ ,  $p = 0.0038$ ,  $MSE = 0.62$ . Subjects showed higher sensitivity when the saccade target was displaced ( $M = 1.57$ ) than when the flanker object was displaced ( $M = 0.93$ ). Second, there was a significant effect of blanking,  $F(1, 6) = 23.55$ ,  $p = 0.0028$ ,  $MSE = 0.49$ . Subjects showed higher sensitivity in the conditions where the objects were present after the saccade ( $M = 1.55$ ) than when the objects were blanked postsaccadically ( $M = 0.95$ ). Third, there was an interaction between saccadic status and session order,  $F(1, 6) = 7.54$ ,  $p = 0.033$ ,  $MSE = 0.62$ . First performing the blanking sessions seems to boost sensitivity specifically for the target object. Finally, and most importantly, the interaction between dynamic status and blanking was significant,  $F(1, 6) = 56.33$ ,  $p = 0.0003$ ,  $MSE = 0.19$ , (Fig. 4). Whereas displacements of the stationary object were detected with the same accuracy when a postsaccadic blank was introduced than without blank, the superior detection of displacements of the translating object in conditions without a blank disappeared completely when the object was absent for only 60 ms after the saccade.

Misattribution data (7.5% in the blank conditions, 3.59% in no-blank conditions) were analyzed separately. An ANOVA was done on the percentage of misattributions with dynamic status (translating vs. stationary), saccadic status (target vs. flanker), and direction of motion (left–right vs. right–left) as within-subject variables and session order as between-subjects variable.

<sup>5</sup> The blank started on average 14 ms before the end of the saccade and lasted 60 ms before the objects were visible again. In the sessions without blanking, the displacement took place during the saccade, on average 14.6 ms before the end of the eye movement.

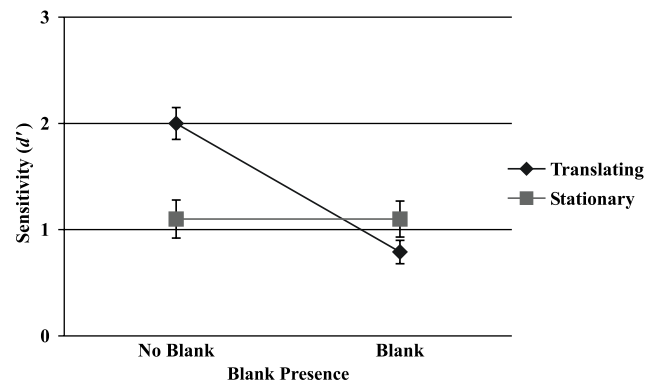


Fig. 4. Sensitivity results ( $d'$ ) from Experiment 2 (means and standard errors) in function of dynamic status of the changed object (translating/stationary) and blank presence (no blank/blank).

For the blank conditions, none of the effects involving the within-subject variables was significant.<sup>6</sup>

#### 4.2. Discussion

Even a 60 ms blank disturbs accurate transsaccadic perception of the motion path. When a translating object is not available after a saccade, even for a period of only 60 ms, the detectability of intrasaccadic displacements drops dramatically. Without blank, the detection of changes in the position of the translating object is much more accurate than the detection of changes in a stationary object, whereas with a 60 ms blank, performance for the moving object is even lower than performance for the stationary object.

For the stationary object, a postsaccadic blank of 60 ms in our paradigm is too short to result in a significant increase in  $d'$  values. Deubel et al. (1996) also reported that the effect of blanking on transsaccadic memory for object position that shows up with blanks of about 250 ms, is reduced when the blanking period is shortened to 50 ms (albeit that in Deubel et al.'s study a 50 ms blank still resulted in better detection of intrasaccadic displacements than in a control condition without blank).

### 5. General discussion

Gysen et al. (2002) found more accurate transsaccadic position coding for translating than for stationary objects as evidenced by higher sensitivity for intrasaccadic displacements of translating objects than for displacements of stationary objects. In the present study, we tested the hypothesis that a motion perception

<sup>6</sup> The percentage of misattributions in the no-blank conditions was small (3.59%) and evenly distributed over stationary and translating objects,  $F(1, 6) = 1.8$ ,  $p = 0.23$ ,  $MSE = 0.015$ .



system with high temporal and spatial resolution, optimally adapted to keep track of translating objects, is responsible for this effect.

In order to make a saccade to a translating target (in contrast to the initiation of a saccade towards a stationary object), the visual system has to take into account that the object changes position during the saccade latency and during the saccade itself. Therefore, motion as well as spatial position information about the translating object probably play a role in saccade generation. This information has to be constantly updated to provide accurate information that can be sent to the saccade system. Immediately after the saccade to the translating object, pursuit starts. This pursuit engagement is closely linked to the saccade and probably relies heavily on acquiring the target and on immediate postsaccadic information (Gardner & Lisberger, 2001). Retinal slip information after the saccade can possibly be an important postsaccadic factor (Ogawa & Fujita, 1997) to update pursuit. Consequently, we hypothesized that our previous findings for the translating object (Gysen et al., 2002) may be based on fast and precise motion processing mechanisms that heavily rely on immediate postsaccadic information to support an accurate and up-to-date transsaccadic perception of the position and motion path of a translating object.

To test this hypothesis we employed blanking, a technique introduced by Deubel et al. (1994). We predicted that the removal of postsaccadic information should enhance displacement detection for stationary objects (as found by Deubel et al., 1996). However, for translating objects we predicted a decrease in performance because the supposedly vital postsaccadic information was removed.

Our predictions were confirmed. In Experiments 1 and 2, we replicated the Deubel et al. (1996) findings for stationary objects: Blanking the stationary object for a certain time after the saccadic eye movement increased sensitivity for intrasaccadic displacements. Moreover, this saccadic enhancement increased as a function of blank duration. For the translating object, blanking had the adverse effect one would expect if postsaccadic information plays a crucial role in transsaccadic position coding. Moreover, this effect was at full strength at even very short blank durations.

Deubel et al. (1996) proposed a revision mechanism as a possible explanation for the better performance for stationary objects in blanking conditions. They suggested that for stationary objects our visual system normally adheres to the assumption of stability across saccadic eye movements. Small position changes are by consequence seldom noticed by the observer. The introduction of a blank forces the visual system to abandon this assumption. A recalibration of the spatial environment is started and position changes can be detected with a higher accuracy. Deubel et al. (1996) re-

ported a gradual effect of the duration of blanking. Small increases in detection with short blanks, higher increases in detection with longer blanks (an asymptote is reached around 200 ms). We also observed this gradual effect for stationary objects.

Another mechanism that can be linked to the effect of blanking on sensitivity for position changes of stationary objects, is the role of confounding intra- and postsaccadic stimulus signals in transsaccadic perception (Judge, Wurtz, & Richmond, 1980). In normal circumstances when there is an object present postsaccadically, the sensory intra- and post-saccadic neural signals are confounded. Hence, due to the confound there is a low sensitivity for intrasaccadic position changes. When a blank is introduced, the postsaccadic object is not immediately present and the confound probably does not come in to play. Hence the position change is better detected.<sup>7</sup> Judge et al. (1980) suggest a confounding effect that is strong until  $\approx 50$  ms after the saccade. If we assume that the confound decreases gradually, the effects for 60 and 220 ms for the stationary object are in line with this explanation.

The results for the translating object in the two blanking experiments reported in this article cannot be explained in terms of Deubel et al.'s (1996) account of the effect of blanking of stationary objects. Our visual system probably does not assume stability for a translating object across saccades in the sense that it does this for stationary objects. Also a description of the data derived from Judge et al.'s (1980) research results, does not seem to account for our findings for translating objects. The effect of a 220 ms blank is at least as strong as the effect of a 60 ms blank, an observation that is at odds with Judge et al.'s (1980) finding that the confounding effect is strong until  $\approx 50$  ms after the saccade.

The data suggest that translating objects are processed transsaccadically by a fast integrating mechanism that relies heavily on postsaccadic information. The temporal window which this system needs postsaccadically, to successfully keep track of a translating object across a saccade, seems very small. Additionally, it is possible that this motion processing system makes use of adjustable gain control settings (Tanaka & Lisberger, 2000). Gardner and Lisberger (2001) propose that pursuit target selection partly uses the control signals for saccades so that the visual motion input from the endpoint region of the saccade is enhanced and serves as input to the pursuit system.

However, this can only be part of the story. The reason is that the effect of blanking was similar for target

<sup>7</sup> Note that Judge et al. (1980) assume that saccadic suppression takes place, but they suggest that masking and confounding are extra factors decreasing intrasaccadic sensitivity. Taking away one of these factors could then improve sensitivity.



and flanker objects.<sup>8</sup> For moving objects sensitivity drops for target as well as for flanker objects. Whereas the effect for the target object can be understood within Gardner and Lisberger's (2001) framework (postsaccadic enhancement of the target region which occurs without blanking is prevented by the blank), the effect for the flanker object does not fit in this picture. In our experiments, presaccadic encoding (before the observer knows which object is going to be the target of the saccade) is the same for the translating object in target and flanker situations. Postsaccadically, however, there is a crucial difference: The translating target object is the object that can receive the postsaccadic gain, while the flanker object probably does not receive this (much) gain. Therefore, blanking probably interferes with two different postsaccadic processes: When the translating object is target of the saccade blanking hinders correctly acquiring the target and getting accurate information to engage the planned pursuit of the translating target object. When a saccade has to be made to the stationary instead of the translating object, blanking hinders the visual system to immediately check (in the periphery) where the translating flanker object is after the saccade. Experiments investigating the effects of different blanking durations on target and flanker objects can probably give more information on why the location of translating objects is processed much more accurately transsaccadically than the location of stationary objects, not only when the moving object is the target of a saccade, but also when it is flanking the saccade target. Furthermore, different blanking durations can give more insight into the timing of postsaccadic processes for stationary as well as translating objects.

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<sup>8</sup> For stationary objects this is more or less conform with Deubel et al. (1998). Specifically, they found that blanking not only improved detection of displacements of stationary saccade targets, but also detection of displacements of distractor objects. Sensitivity for flanker and target objects remained the same (with a 60 ms blank) or increased (with a 220 ms blank) relative to no-blanking conditions. This seems to suggest that the enhancement is similar for stationary targets and flankers, which (following Deubel et al., 1998) implies accurate (implicit) position coding of bystander stationary objects. Still, we want to remark that the enhancement effect was slightly higher for the stationary target than flanker object.

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## Appendix A

To obtain  $d'$  we followed the constant ratio rule (MacMillan & Creelman, 1991, pp. 243–245). From the overall contingency table produced by the three stimulus types (shift translating, shift stationary, no shift)  $\times$  3 response types (translating shifted, stationary shifted, nothing shifted), we extracted two  $2 \times 2$  tables (shift translating vs. no shift  $\times$  translating shifted vs. nothing shifted, and shift stationary vs. no shift  $\times$  stationary shifted vs. nothing shifted). This was done separately for each subject in each of the conditions produced by the factorial combination of blanking (blank vs. no blank), saccadic status (target vs. flanker), and direction of motion (left-to-right vs. right-to-left). Table 1 illustrates a  $3 \times 3$  contingency table for the no blanking  $\times$  target (translating object)  $\times$  L–R motion condition in

Table 1  
3  $\times$  3 contingency table presenting raw response frequencies in the no blank  $\times$  translating saccade target  $\times$  L–R motion direction condition of Experiment 1

Stimulus type	Response type			$N_{\max} = 32$
	Translating shifted	Stationary shifted	Nothing shifted	
Shift translating	<b>28</b>	0	<b>3</b>	31
Shift stationary	1	<b>9</b>	<b>15</b>	25
No shift	<b>1</b>	<b>1</b>	<b>28</b>	30

The frequency of answering 'Translating shifted', 'Stationary shifted', or 'Nothing shifted' is plotted per stimulus type (shift translating, shift stationary, no shift) for 1 subject. The maximum frequency value per row is 32 (32 trials per condition). The extracted  $2 \times 2$  tables are indicated in bold type.

Table 2  
 $2 \times 2$  contingency table for the translating object (extracted from Table 1), presenting raw response frequencies in the no blank  $\times$  translating saccade target  $\times$  L–R motion direction condition of Experiment 1 (The frequency of answering 'Translating shifted' or 'Nothing shifted' is plotted per stimulus type (shift translating, no shift) for 1 subject.)

Stimulus type	Response type		Sum of rows
	Translating shifted	Nothing shifted	
Shift translating	28	3	31
No shift	1	28	29

Formula  $d'$  (MacMillan & Creelman, 1991, p. 9):  $d' = Z(\text{hit}) - Z(\text{false alarm})$ . Hits and false alarms for the translating object in the target  $\times$  L–R direction of motion condition are respectively 0.9 (28/31) and 0.034 (1/29).  $d'$  then becomes:  $1.29 - (-1.82) = 3.11$ .

Table 3

2 × 2 contingency table for the stationary object (extracted from Table 1), presenting raw response frequencies in the no blank × translating saccade target × L–R motion direction condition of Experiment 1 (The frequency of answering ‘Stationary shifted’ or ‘Nothing shifted’ is plotted per stimulus type (shift stationary, no shift) for 1 subject.)

Stimulus type	Response type		Sum of rows
	Stationary shifted	Nothing shifted	
Shift stationary	9	15	24
No shift	1	28	29

Hits and false alarms for the stationary object in the target × L–R direction of motion condition are respectively 0.37 (9/24) and 0.034 (1/29).  $d'$  then becomes:  $-0.33 - (-1.82) = 1.49'$ .

Experiment 1. Tables 2 and 3 are the extracted 2 × 2 tables for this condition.

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