The saccadic size-latency phenomenon explored: Proximal target size is a determining factor in the saccade latency

J.P. De Vries [a,*], R. Azadi [b], M.R. Harwood [a,c]

[a] Department of Biology, City College of New York, City University of New York, NY, USA
[b] Graduate Center for Vision Research, SUNY College of Optometry, New York, NY, USA
[c] Department of Psychology, University of East London, London, UK

ABSTRACT

Saccade latencies are known to increase for targets presented close to fixation. Recently, it was shown that not only target eccentricity, but the size of a proximal saccade target also plays a crucial role: latencies increase rapidly with increasing target size. Interestingly, these latency increases are greater than those typically found for other supra-threshold manipulations of target properties. Here we evaluate to what extent this phenomenon is distinct from known delays in saccade initiation and whether the phenomenon is truly related to the size of a proximal target. In Experiment 1 we focus on the importance of the required amplitude. Employing a saccade adaptation paradigm we find that the required amplitude is not a determining factor. Focusing on the role of size, in Experiment 2, we find that while latency increases are strongest for targets elongated in the direction of the fovea, elongations perpendicular to this direction also lead to an increase in latencies. Finally, in Experiment 3 we verify that the latency increases are driven by the properties of the saccade target rather than visual input in general. Together these experiments provide converging evidence that the current phenomenon is both novel and a consequence of the relation between proximal target size and its eccentricity.

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1. Introduction

The limited resolution of the visual periphery and peripheral crowding requires observers to make saccadic eye movements to inspect objects of a scene in detail. While the typical latency of eye movements to a new visual stimulus is around 200 ms (in laboratory setups), it has been shown that this number rapidly increases for targets within 2° of the current fixation. This phenomenon was already revealed over four decades ago (Kalesnykas & Hallett, 1994; Wyman & Steinman, 1973). However, two recent studies have provided an important extension: Aside from the required saccade amplitude, proximal target size appears to also be a determining factor of the saccade latency (Harwood, Madelain, Krauzlis, & Wallman, 2008; Madelain, Krauzlis, & Wallman, 2005). In their experiments, observers were required to attend to, and track two concentric rings of different sizes. The two rings were made up of separate segments, allowing them to rotate, and observers had to either attend to the larger ring or the smaller ring. During the tracking, the rings would step and contingent on the step the number of segments in the ring would briefly change. Observers had to regain fixation and report the number of segments after the step of the attended ring. It was found that saccades contingent on the step had drastically different latencies depending on which ring was attended: Latencies in the attend-to large condition were considerably longer than in the attend-to small condition (Madelain et al., 2005). Interestingly, Harwood et al., 2008, uncovered a striking relation between the latency, size and eccentricity of the target: While latencies vary considerably depending on both absolute eccentricity and ring size, evaluating latencies in terms of the amplitude of the step in proportion to the size of the target there appears to be a consistent response time according to this step-size ratio (See Fig. 1 for more information).

As latency differences in Madelain et al. and Harwood et al. typically exceed 100 ms and reach as high as 200 ms, the fluctuations associated with this *size-latency* phenomenon are considerable. While large latency increases have been found previously by lowering the contrast of a saccade target (e.g. Ludwig, Gilchrist, & McSorley, 2004), phenomena based on supra-threshold stimuli typically cause increases on a more limited scale. Inhibition of return, for instance, is typically associated with delays in saccade execution between 10 and 40 ms (see for an overview: Klein,

* Corresponding author.
    E-mail address: vriesdejelmer@gmail.com (J.P. De Vries).
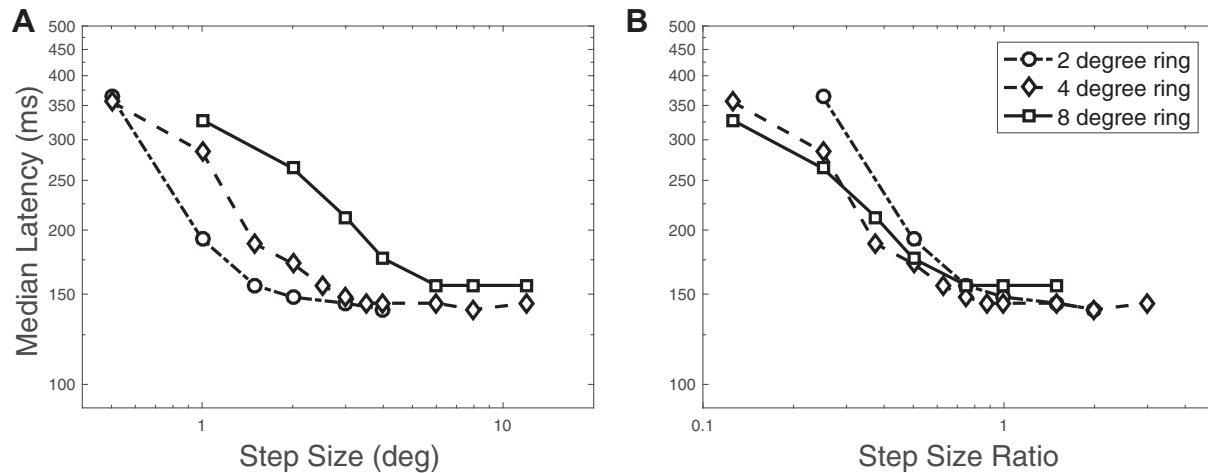
Fig. 1. Median latencies for stepping rings of 3 different sizes for a typical observer (data replotted from Harwood et al., 2008). Employing eight similar attentional paradigms Harwood et al. extensively varied the combination of target size and eccentricity. While latencies for targets at a set eccentricity vary as a function of size, expressing the saccade latency as a function of amplitude divided by ring size (step size ratio) results in highly similar curves for different ring sizes. For the plotted data, the observer had to fixate a ring and make a saccade as soon as it stepped. The ring was segmented, allowing it to rotate, and the number of breaks changed for 150 ms contingent on a step away from fixation. Observers had to report the transient number of breaks (2AFC) at the end of each trial. In A the median latencies are plotted as a function absolute step size for each ring diameter. In B the same data is plotted as a function of step size divided by the ring diameter. As can be seen median latencies are highly similar for all three-ring sizes when the step size is normalized by the stimulus size.

2000). Remote distractors that onset around the time of the target in the contralateral hemifield lead to a latency increase of around 20–30 ms in latencies (Walker, Kentridge, & Findlay, 1995; Weber & Fischer, 1994). This increase just exceeds 50 ms when the distractor is placed at fixation (Walker, Deubel, Schneider, & Findlay, 1997). A manipulation that has been shown to cause more considerable fluctuations in latencies is the gap effect. Here the removal of the fixation marker 200 ms prior to target onset decreases latencies considerably. However, while the initial findings surrounding the gap effect showed latency decreases up to 100 ms (Saslow, 1967; Weber, Aiple, Fischer, & Latanov, 1992) later findings reported much smaller effects (Reuter-Lorenz, Hughes, & Fendrich, 1991). It is likely that aside from the benefit of releasing inhibition at fixation, the offset serves as a warning signal for the upcoming stimulus (Fendrich, Demirel, & Danziger, 1999; Reuter-Lorenz, Oonk, Barnes, & Hughes, 1995). Hence, the great reduction in latencies appears to be a compound of two effects. Considering the relatively large latency differences associated with the current phenomenon it is a highly interesting candidate for advancing understanding of the sensorimotor decision process in general.

The current paper evaluates whether the *size-latency phenomenon* is distinct from previously reported phenomena in the literature and what the determining factors are. While the reported measure is the saccade latency, in both the papers by Madelain et al. and Harwood et al. the independent variable was encapsulated in an additional attentional task. Potentially, observers employing conscious strategies to cope with the attentional task could have caused the latency difference.[1] Therefore, it is important to verify the existence of the phenomenon in simple saccade tasks. Previous studies requiring only saccades towards spatially extended targets have either reported no size-effect on saccade latency (Kowler & Blaser, 1995; Mcgowan, Kowler, Sharma, & Chubb, 1998), or much weaker effects than found in the studies of Madelain et al. and Harwood et al. (Dick, Ostendorf, Kraft, & Ploner, 2004;

Ploner, Ostendorf, & Dick, 2004). However, as we have argued previously, these absent or weak effects (latency differences < 25 ms) were likely due to size-distance variations in the asymptotic short-latency region of Fig. 1 (e.g. 13 out of 15 of the size/eccentricity conditions in Ploner et al. (2004)). Finally, an indication that the current phenomenon extends to regular saccade preparation (i.e. without additional tasks) comes from latencies for two observers who performed the ring task, without any additional attentional task (Harwood et al., 2008, supplemental materials). The purpose of the current paper is to evaluate whether the findings are indeed generally applicable (i.e. hold for saccades even in simple tasks) and whether it is truly a novel phenomenon in the sense that it cannot be explained by established inhibitory mechanisms of saccade initiation.

Referring to the current phenomenon as the size-latency phenomenon suggests that the phenomenon mainly relies on target size. However, the strong latency increases found when reducing saccade amplitudes raise the question to what extent the current phenomenon is dependent on the required saccade amplitude. In Experiment 1 we focus on this question by employing a saccade adaptation paradigm. In two separate sessions, large proximal targets are either stepped backward or forward, upon saccade initiation. Previewing these results we find that despite strongly adapting amplitudes, latencies remain primarily unaffected. Given the strong reliance on visual target properties in Experiment 2 we evaluate whether it is correct to consider size as the determining factor; we evaluate how increasing target size in different directions affects latencies. As this again shows a strong reliance on visual input in general, in Experiment 3 we verify that the phenomenon relies on the properties of the saccade target and not visual input per se.

2. Experiment 1: required saccade amplitude

What is the role of the required saccade amplitude in the size-latency phenomenon? As mentioned above, several studies have already found that latencies increase for more proximal targets. While the size-latency phenomenon appears distinct from this, as it relies on target properties as well as eccentricity, it is unclear what the role of the required saccade amplitude is. Therefore, in

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[1] For instance, when the small ring steps, the visual acuity of the target diminishes to the extent where an observer may require a saccade to complete the segment counting task. Conversely, when the large ring steps, the observer's fixation is still within the ring and the strategy may be to first complete the attentional task and to only prepare the saccade afterwards, hence delaying the execution of the saccade in the large ring condition.