

Holle Kirchner · Hans Colonius

Cognitive control can modulate intersensory facilitation: speeding up visual antisaccades with an auditory distractor

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Abstract Although saccadic reaction times to a visual stimulus are facilitated if an auditory accompanying stimulus is presented at the same location, this intersensory facilitation effect (IFE) has not been explored for antisaccades (saccades directed opposite to a visual target). In this study participants were asked to make an antisaccade opposite to a point of light presented right or left of fixation while accompanied by an auditory stimulus either at the same or at the opposite location with different stimulus onset asynchronies. Antisaccade reaction times for unimodal auditory and bimodal stimuli were shorter than for unimodal visual stimulation, in line with prosaccade studies. The auditory accompanying stimulus afforded antisaccade reaction times approximately as fast as prosaccades in the direction of a visual target, especially when it was presented 40 ms before the spatially congruent visual target. Moreover, predictiveness of the target position facilitated performance only when the auditory stimulus was presented at the opposite location and 40 ms before the visual target (interstimulus contingency effect). We conclude that intersensory facilitation is a mandatory, bottom-up process, but in the particular case of a response conflict due to a visual target, IFE can be shown to be modulated by the predictability of the target location.

Keywords Multisensory interaction · Interstimulus contingencies · Antisaccades

Introduction

Saccadic eye movements in the direction of a visual target are facilitated if an auditory accompanying stimulus is presented in spatial and temporal proximity (Frens et al. 1995; Colonius and Arndt 2001). Although there exists a wealth of evidence for this intersensory facilitation effect (IFE), it has not been explored for antisaccades. In the antisaccade task, participants are asked to make a saccade with the same amplitude, but in the direction opposite to that of a visual target. In this case, saccadic reaction times are prolonged by approximately 60 ms, possibly because of two factors:

- 1) the need for inhibition of an automatic saccade response in the direction of the visual target (ocular inhibition, OI), and
- 2) allocation of covert attention to the saccade landing position opposite to the visual target (Everling and Fischer 1998; Olk and Kingstone 2003; Schall 2004).

In this study we asked which of these components in the programming of an antisaccade can be modulated by IFE. Human participants were instructed to direct their gaze opposite to a visual target in the presence of an auditory distractor, which was presented either spatially congruent or incongruent (at the opposite location) to the target. When, for spatial incongruence, participants are instructed to saccade to the auditory stimulus and to consider the visual a distractor, saccadic reaction times are prolonged compared with unimodal visual reaction times (Lueck et al. 1990; Cornel and Munoz 1996). Kirchner and Colonius (2004) argued that participants programmed a voluntary saccade in the direction of the auditory target while having to inhibit the location of the visual distractor. This ocular inhibition, however, was assumed to be less effective than in an antisaccade task leading to overall faster responses to the auditory target compared with antisaccade latencies (Kristjánsson et al. 2001). Note that, in contrast with the antisaccade task, subjects were asked to ignore the visual stimulus and base

H. Kirchner · H. Colonius
Department of Psychology, Oldenburg University, Ammerländer
Heerstrasse 111-114, 26111 Oldenburg, Germany

H. Kirchner (✉)
Centre de Recherche Cerveau et Cognition,
133 route de Narbonne, 31062 Toulouse Cedex, France
E-mail: holle.kirchner@cerco.ups-tlse.fr
Tel.: +33-5-62172802
Fax: +33-5-62172809

their performance on the location of the auditory target. The difference between reaction times for the two tasks could thus also be because of the second component in the programming of an antisaccade, i.e. the allocation of covert attention opposite to the visual target, because this component should not apply, or much less so, in the auditory prosaccade task. The objective of this study was to directly test this possibility by using the identical experimental procedure as in the auditory prosaccade task, but instructing subjects to make an antisaccade opposite to the visual target.

A second objective of this study relates to the modularity of IFE. In natural situations stimuli from different modalities often occur correlated in space and time. Thus, we asked whether participants can use interstimulus contingencies to reduce the inhibitory effect resulting from choice of gaze direction. Interstimulus contingency (ISC) is defined as the conditional probability that the visual target is presented at the same location as the auditory distractor. Thus, the location of the distractor is predictive of the target location to different degrees. We hypothesized that the amount of ocular inhibition is inversely related to the predictability of the target location.

Materials and methods

Participants

Three students (age 21–26 years) of the University of Oldenburg took part in the experiment and were either paid or received partial course credit for their involvement. All had right eye dominance, normal or corrected-to-normal vision, and normal hearing. The procedure was approved by the local human-studies committee in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants gave their informed consent before their inclusion in the study.

Experimental set-up

Participants were seated in a small, darkened, sound-attenuated booth with their head fixed by a dental impression plate. Visual stimuli were presented on a 37-in monitor located outside the booth (viewing distance 57 cm). Auditory stimuli were presented via headphones by a high-performance sound card. Stimulus presentation and data acquisition were synchronized with the onset of the visual stimulus determined by the monitor update rate to guarantee exact temporal presentation of the stimuli.

Procedure

White dots with a diameter of 0.1° served as visual stimulus and fixation point. They were presented with a

luminance of 11 cd m^{-2} on a dark background. Auditory stimuli consisted in white noise (5 ms rise time, 58 dB SPL) convolved with head-related transfer functions of a dummy head resulting in virtual displays at 15° right or left of fixation.

A trial started with a fixation point, which, after a random time interval, was replaced by the target presented for 500 ms, 15° right or left of fixation. In bimodal trials, stimuli were presented with equal probability at each side of fixation, either at the same (“congruent”) or at the opposite (“incongruent”) location. Stimulus onset asynchrony (SOA) was varied so that the auditory stimulus was presented simultaneously, or 40 ms before (–) or after (+) the visual target. The task was to make an eye movement as quickly and as accurately as possible opposite to the visual target and to use the auditory distractor as a possible, albeit unreliable, cue for the location of the visual target. Interstimulus contingencies of 20–80, 50–50, and 80–20 were employed in separate blocks of trials resulting in a minimum of 48 trials per condition and participant. The order of blocks was randomized between participants. To familiarize them with the task participants took three practice sessions with the 50–50 ISC. Saccades directed opposite to unimodal visual or auditory targets were measured in separate blocks at the end of the sessions.

Response recording and detection

Eye movements were measured with an infrared light reflecting eye-tracker providing an analogue signal of the eye position that was digitized at a rate of 1 kHz and stored on a PC. Saccade onsets and offsets were identified automatically, using velocity criteria (50° s^{-1} for onsets and 20° s^{-1} for offsets). The accuracy of the computer-generated marks was verified by the experimenter. Saccadic reaction time (SRT) was defined as the time between the onset of the target and the onset of the saccade.

All effects were verified across participants by an ANOVA on the 5%-level with stimulus modality, SOA and spatial congruence, or spatial congruence and interstimulus contingency as repeated factors.

Results

Visual-auditory interaction effects

The analysis of stimulus modality effects revealed mean antisaccade reaction times opposite to unimodal auditory targets as short (231 ms) as in bimodal trials (230 ms) which in turn were significantly shorter than unimodal visual antisaccades (272 ms; $F_{(1,2)} = 80.6$, $P < 0.012$). The auditory distractor thus facilitated saccades opposite to the visual target, in accord with IFE in prosaccades.

ANOVA on the bimodal trials with SOA (−40, 0, and +40 ms) and spatial congruence (congruent versus incongruent) as repeated factor revealed two significant main effects and a significant interaction effect. The main effect of SOA indicated shorter antisaccade latencies the earlier the auditory distractor was presented before the visual target ($F_{(2,4)} = 155.5$, $P < 0.006$; Fig. 1). The main effect of spatial congruence indicated 14 ms shorter antisaccade reaction times to congruent than to incongruent stimulation ($F_{(1,2)} = 26.7$, $P < 0.035$; Fig. 1). Finally, the interaction effect of SOA and spatial congruence ($F_{(2,4)} = 28.5$, $P < 0.004$) showed that the effect of spatial congruence was largest in SOA = −40 ms (22 ms, $F_{(1,2)} = 61.7$, $P < 0.016$), smaller in SOA = 0 ms (13 ms, $F_{(1,2)} = 28.8$, $P < 0.033$), and vanished in SOA = +40 ms ($F_{(1,2)} = 2.9$, $P > 0.1$, n.s.). Comparison with prosaccade reaction times to unimodal visual stimulation (Kirchner and Colonius 2004) further showed that the antisaccade latencies in the spatially congruent trials of SOA = −40 ms were approximately as fast as unimodal visual prosaccades ($F_{(1,746)} = 1.8$, $P > 0.1$, n.s.; Fig. 1).

Interstimulus contingency effects

The measurement of spatial interstimulus contingencies implies the systematic variation of spatial congruence and predictability of target location. To disentangle these effects we represent the data as spatially congruent versus incongruent, and across the different contingency blocks in terms of predictability of target location, irrespective of spatial congruence. In so doing, we are able to prevent confounding the more general effect of spatial congruence with the more specific effect of target predictability. In this sense, the rare trials of 80–20 ISC-blocks in which the stimuli were spatially incongruent,

and the rare trials of 20–80 ISC-blocks in which the stimuli were spatially congruent will both be called “20% predictive” of the target location.

ANOVA on the bimodal trials with spatial congruence (congruent versus incongruent) and predictability (20, 50, or 80%) as repeated factors revealed a significant main effect of spatial congruence ($F_{(1,2)} = 44.5$, $P < 0.022$; Fig. 2), indicating shorter antisaccade reaction times with spatially congruent stimulation. The second main effect, and the interaction effect of spatial congruence and interstimulus contingency did not reach significance. However, separate analyses of the bimodal data in each SOA condition showed that in the spatially incongruent trials of SOA = −40 ms, antisaccade reaction times were modulated by the predictability of the target location (Fig. 2): 80% < 50% (12 ms, $F_{(1,2)} = 15.1$, $P < 0.06$), 80% < 20% (17 ms, $F_{(1,2)} = 14.8$, $P < 0.062$), but 50% = 20% ($F_{(1,2)} = 2.7$, $P > 0.1$, n.s.). An analysis of the direction errors in the spatially incongruent trials of SOA = −40 ms compared with the overall number of trials in each contingency condition showed that our conclusion was not invalidated by a speed–accuracy trade-off (Fig. 2). Finally, in the spatially congruent trials of SOA = −40 ms, and in the remaining SOA conditions no effect of interstimulus contingency was obtained.

Discussion

The presence of an auditory distractor facilitates anti-saccade reaction times opposite to a visual target. In accord with results on prosaccades (Frens et al. 1995; Colonius and Arndt 2001), this intersensory facilitation effect was pronounced if the distractor was presented at the same location as the target, compared to opposite

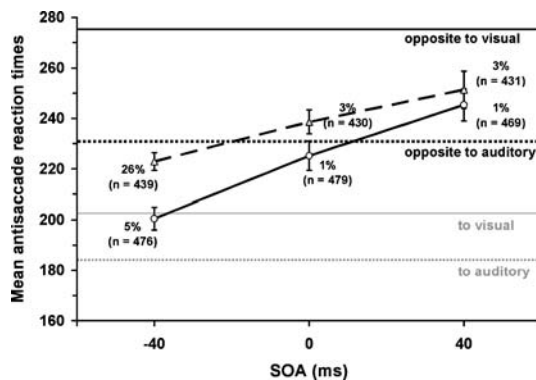


Fig. 1 Intersensory facilitation effects in antisaccades. Stimulus onset asynchrony (SOA) was varied such that the auditory distractor was presented 40 ms before (−), simultaneously with, or 40 ms after (+) the visual target, either at the same location (circles) or at the opposite location (triangles). Mean antisaccade reaction times and error rates in the bimodal trials are compared with unimodal visual (upper black line) and auditory (black dotted line) antisaccade latencies. Unimodal visual (grey line) and auditory (grey dotted line) prosaccade latencies are reprinted with permission from Kirchner and Colonius (2004)

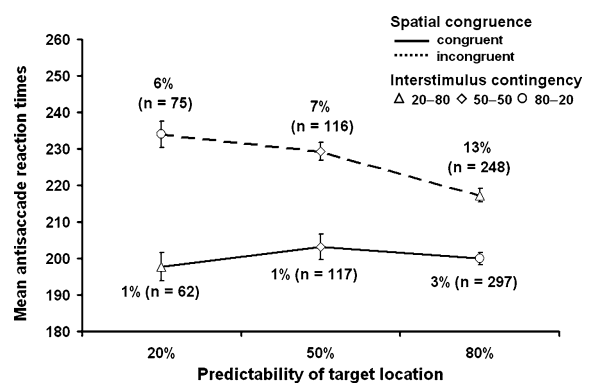


Fig. 2 Effects of predictability of target location on mean antisaccade reaction times and error rates in SOA = −40 ms. In 80–20 interstimulus contingency (ISC, circles) (respectively, in 20–80 ISC (triangles)), the visual target was presented spatially congruent to the auditory stimulus in 80% (respectively, 20%) of the trials, and it was presented incongruent to the auditory stimulus in the remaining 20% (80%) of the trials. The 80% predictability level thus contains both congruent trials from 80–20 ISC and incongruent trials from 20–80 ISC

locations. The auditory distractor had a warning signal effect in that antisaccade reaction times were shorter the earlier it was presented before the visual target (Ross and Ross 1981). These results clearly indicate that IFE effects are sensory leading to overall shorter saccadic reaction times irrespective of whether the two stimuli are presented at the saccade endpoint such as in a prosaccade task, or whether both stimuli are presented opposite to the saccade endpoint such as in the present antisaccade task (Fecteau et al. 2004).

Interestingly, if the auditory distractor was presented at the same location, but 40 ms before the visual target, antisaccade reaction times were approximately as fast as unimodal visual prosaccades. It has already been reported that antisaccade reaction times can be essentially equivalent to prosaccade reaction times, but only if just one possible target is present (Kveraga et al. 2002). This result was explained with the notion of a prepared response, because the intention to make a saccade to a known location can be maintained in memory and then needs only be triggered by the onset of the target. However, even if the auditory distractor in this study served as a warning signal thereby attracting attention, it would be premature to conclude that it also served to directly trigger the antisaccade response, because the participants would then have committed even more errors in the spatially incongruent condition than they actually did (26%), given the fact that in half of the trials the visual target was presented opposite to the auditory cue. A more plausible explanation relates to the observation that antisaccade reaction times can be reduced substantially when a discrimination stimulus is presented just 100–300 ms before the antisaccade target (Kristjánsson et al. 2001). Assuming that the preparation of a reflexive prosaccade prolongs the initiation of an antisaccade, it was argued that the secondary discrimination task interfered with the reflexive prosaccade so that attention-demanding disengagement from that reflex was not needed, thereby leading to the paradoxical speeding up of the antisaccade (Kristjánsson et al. 2001). If we apply this logic to our task, we might argue that as soon as the auditory distractor was present, attention was cued to that location, and that this attentional effect might directly have interfered with the preparation of the prosaccade so that, when the visual target arrived, the appropriate antisaccade only needed to be triggered from memory (1. visual target left, move right, or 2. visual target right, move left). This explanation would account for the extremely fast antisaccade reaction times and the small number of prosaccade errors in the spatially congruent trials. Note, however, that this also implies that the intersensory facilitation effect reported here affected the ocular inhibition component in the programming of an antisaccade rather than the covert attention part, at least in the particular case of a short temporal offset between the auditory cue and visual target. Further research is needed to address the issue of to what extent an explanation with more emphasis

on sensory aspects, yet focussing on competitive interactions between prosaccades and antisaccades, could account for the results (Hunt et al. 2004; Kristjánsson et al. 2004; Massen 2004).

The hypothesis that the auditory cue interfered with the preparation of a reflexive prosaccade leads to further insight into the processing of interstimulus contingencies, because the auditory cue also contained this conditional probability information. Indeed, we might assume that the interference with the prosaccade program, and thus ocular inhibition, by the auditory cue was weighted by the predictability of target location, thereby leading to faster antisaccade reaction times in instances of high as opposed to low predictability, in line with a previous report on auditory prosaccades (Kirchner and Colonius 2004). In contrast with the previous study, here the modularity of ocular inhibition by predictability was observed only if the auditory distractor was presented at the opposite location and 40 ms before the visual target, whereas with auditory prosaccades predictability effects were found to be independent of temporal proximity, but again only occurred if there was spatial incongruence between the visual and auditory stimuli (Kirchner and Colonius 2004). Also, the difference between mean reaction times for the two experiments was only marginal (7 ms). The comparison with auditory prosaccades thus indicates that, at least in the particular condition of a short offset between the auditory cue and visual target, antisaccades are not prolonged by an additional shift in covert attention nor, alternatively, by pronounced ocular inhibition, contrary to our hypothesis. Rather, it seems that the modularity of IFE by predictability of the target location becomes visible only when there is a response conflict between the natural predisposition of the oculomotor system for a visual target (Groh et al. 2001) and a spatially disparate auditory cue which needs to be considered, either by instruction such as in the auditory prosaccade task, or which automatically attracts attention, for example when there is a short temporal offset between the cue and visual target in the present antisaccade task. This suggests that IFE is a mandatory, bottom-up process (Wallace et al. 2004; Shore and Simic this issue), but that, nevertheless, in case of a response conflict due to a visual target IFE can be shown to be modulated by the predictability of the target location.

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References

- Colonius H, Arndt P (2001) A two-stage model for visual-auditory interaction in saccadic latencies. *Percept Psychophys* 63:126–147
- Corneil BD, Munoz DP (1996) The influence of auditory and visual distractors on human orienting gaze shifts. *J Neurosci* 16:8193–8207

- Everling S, Fischer B (1998) The antisaccade: a review of basic research and clinical studies. *Neuropsychologia* 36:885–899
- Fecteau JH, Au C, Armstrong IT, Munoz DP (2004) Sensory biases produce alternation advantage found in sequential saccadic eye movement tasks. *Exp Brain Res* 159:84–91
- Frens MA, Van Opstal AJ, Van der Willigen RF (1995) Spatial and temporal factors determine auditory–visual interactions in human saccadic eye movements. *Percept Psychophys* 57:802–816
- Groh JM, Trause AS, Underhill AM, Clark KR, Inati S (2001) Eye position influences auditory responses in primate inferior colliculus. *Neuron* 29:509–518
- Hunt AR, Olk B, von Muhlenen A, Kingstone A (2004) Integration of competing saccade programs. *Brain Res Cogn Brain Res* 19:206–208
- Kirchner H, Colonius H (2004) Predictiveness of a visual distractor modulates saccadic responses to auditory targets. *Exp Brain Res* 155:257–260
- Kristjánsson A, Chen Y, Nakayama K (2001) Less attention is more in the preparation of antisaccades, but not prosaccades. *Nat Neurosci* 4:1037–1042
- Kristjánsson A, Vandenbroucke MW, Driver J (2004) When pros become cons for anti-versus prosaccades: factors with opposite or common effects on different saccade types. *Exp Brain Res* 155:231–244
- Kveraga K, Boucher L, Hughes HC (2002) Saccades operate in violation of Hick's law. *Exp Brain Res* 146:307–314
- Lueck CJ, Crawford TJ, Savage CJ, Kennard C (1990) Auditory-visual interaction in the generation of saccades in man. *Exp Brain Res* 82:149–157
- Massen C (2004) Parallel programming of exogenous and endogenous components in the antisaccade task. *Q J Exp Psychol A* 57:475–498
- Olk B, Kingstone A (2003) Why are antisaccades slower than prosaccades? A novel finding using a new paradigm. *Neuroreport* 14:151–155
- Ross SM, Ross LE (1981) Saccade latency and warning signals: effects of auditory and visual stimulus onset and offset. *Percept Psychophys* 29:429–437
- Schall JD (2004) On the role of frontal eye field in guiding attention and saccades. *Vis Res* 44:1453–1467
- Shore D, Simic N (this issue) Visuotactile congruency is unaffected by probability of congruency: support for a sensory locus of integration
- Wallace MT, Roberson GE, Hairston WD, Stein BE, Vaughan JW, Schirillo JA (2004) Unifying multisensory signals across time and space. *Exp Brain Res* 158:252–258