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RESEARCH NOTES

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Cognitive demand affects the gain of the torsional optokinetic response

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Abstract Cognitive tasks such as mental arithmetic and fixation of imagined targets are known to affect vestibular nystagmus. Here we show that another cognitive task—subject's active control of the rotation of a single moving visual line in an otherwise darkened room—influences the gain of the torsional optokinetic response to that single moving visual line.

Keywords Optokinetic torsion · Entrainment · Cognitive

Introduction

When subjects control the rotation of a single visual line around the visual axis, torsional movements of the eyes in the same direction as the stimulus rotation are induced: this optokinetic phenomenon has been termed 'entrainment' (Mezey et al. 2004). Entrainment has a low gain, where gain is defined as the ratio of the change in eye position to the change in stimulus position (i.e. a positional gain rather than a velocity gain) (Mezey et al. 2004). Entrainment has properties which appear to differ from those of standard optokinetic responses, for example an increase in the magnitude of gain closer to target meridians (Mezey et al. 2004).

Torsional responses to a moving visual line have previously been shown to be affected by various factors, including rotation speed, the size of the visual stimulus and the instructions given to subjects (Howard and Templeton 1964; Honrubia et al. 1968; Wade et al. 1991). In this study we compared the torsional responses to a rotating visual line where the rotation of the line was under the subject's control (Active condition) with the torsional responses to the same line when subjects had no control over its movement (Passive condition). A control condition was also included where the line rotated passively, yet subjects performed the same muscular task as in the Active condition. In all conditions subjects fixated the centre dot of the line, around which the line rotated.

We found the gain of the torsional eye movement response was significantly greater when subjects actively controlled the rotation of the single visual line than when they passively viewed the same stimulus. This result is another example of how important cognitive tasks are in determining the response of basic oculomotor control mechanisms.

Materials and methods

Subjects

Participants were six adults (mean=30 years, SD=16 years), with normal or corrected-to-normal vision. None reported any history of auditory, neurological, visual or vestibular dysfunction, aside from normal refractive errors. During testing subjects were unable to wear corrective lenses, owing to the proximity of the video cameras for measuring eye movements, but all subjects were still able to see the visual line at the standard distance of 68 cm and to make accurate settings to horizontal. All procedures were in accordance with the Declaration of Helsinki and were approved by the University of Sydney Human Ethics Committee. Subjects gave informed written consent and were free to terminate testing at any time.

Visual stimulus

The visual line consisted of 11 blue LEDs (each of diameter 2.4 mm), spaced 23 mm apart (so the visual line had total length of 230 mm and subtended a visual angle of 19.6° at the viewing distance of 68 cm) mounted on a lightweight plastic rod covered with non-reflective black velvet. The line was placed centrally at the subject's eye level, and testing was conducted in an otherwise darkened room. The visual line was mounted on the axis of a computer-controlled stepper motor and was programmed to rotate about the central LED in the subject's coronal plane at a constant speed of 4.8°/s through an angle of 20° in either a clockwise (CW)

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or counter-clockwise (CCW) direction from the subject's point of view. LabVIEW software controlled and recorded these rotations.

Procedure

Each subject wore an individually moulded San-Splint thermoplastic mask (Surgical Synergies, Regents Park), on which infrared-sensitive CCD video cameras (Panasonic WV-CD1E) were mounted. Each eye was flooded with an infrared light, and half-silvered mirrors (Coolbeam; OCLI, Santa Rosa) reflected images of the eyes into the cameras, while allowing subjects full view of the stimulus. Images were recorded on videotape and processed off-line (see next section). To eliminate spurious torsion associated with dilating pupils, subjects' pupils were constricted with two to three drops of pilocarpine nitrate (2.0% w/v; Chauvin Pharmaceuticals, UK) topically administered 30 min prior to testing. Pilocarpine has been previously shown not to affect entrainment (Mezey et al. 2004). Subjects were seated with head erect and were stabilized by head and shoulder supports.

Immediately prior to each testing session the visual line was set to exact gravitational horizontal, determined by a carpenter's level attached to the top of the visual line. All subsequent stimulus movements were logged with respect to this initial position. Testing began with 1 min of baseline in which ocular torsion was measured while subjects fixated the central LED. After the baseline data were collected, experimental conditions were fully explained and subjects were given practice trials of each condition before the commencement of the test conditions.

There were three test conditions: Active, Passive and Effort. During all conditions subjects were instructed to fixate the central LED, not to scan along the visual line, and to minimise blinking. In the Active condition, subjects were instructed to rotate the line to visually perceived horizontal (VPH) in either a CW or CCW direction, by depressing either the left or right button, respectively, on a three-button mouse, in one smooth movement, with no backtracking (bracketing), until the visual stimulus was at VPH, then to release that mouse button and push the centre button to begin the next setting. In the Passive condition, subjects were instructed to simply watch the central LED as the visual line automatically rotated to horizontal in either a CW or CCW direction. In the Effort condition, subjects were instructed that although the visual line would move as in the Passive condition, they were nevertheless to hold down the corresponding mouse button as if setting the visual line to VPH. Each condition had 16 repeats, 8 CW and 8 CCW. The presentation of the CW and CCW stimuli was randomised for each subject within each condition, and the presentation of each condition was randomised between subjects.

Eye movement analysis

Three-dimensional eye position was measured using the VidEyeO videooculographic system, a modification of the Video Torsion Measurement system which was developed and calibrated to an accuracy of 0.1° and sampling rate of approximately 25 Hz in this laboratory (Moore et al. 1991, 1996). Ocular torsional position was measured through polar cross-correlation of the grey-level distribution along an iral circumference (Moore et al. 1996).

Efficient removal of blinks, saccades and quick phases was required for quantitative analysis of eye movements, and was assisted by means of a custom-designed desaccading program (Holden et al. 1992). The desaccaded data were then smoothed using a lowess filter, in which data values were replaced by values of a local polynomial fitted to torsion versus time using robust weighted least squares (Cleveland 1979). Any remaining quick phases were removed manually after being identified by a change in sign of the slope of torsion versus time, persisting for three or more data points.

The smoothed, desaccaded ocular torsion measures were then synchronised exactly with the stimulus position measures using S-Plus 2000 for Windows. To quantify the gain of the torsional response, each stimulus movement trial (lasting approximately 5 s) was divided into four components of 5° of stimulus movement comprising approximately 20 data points each. Least-squares linear

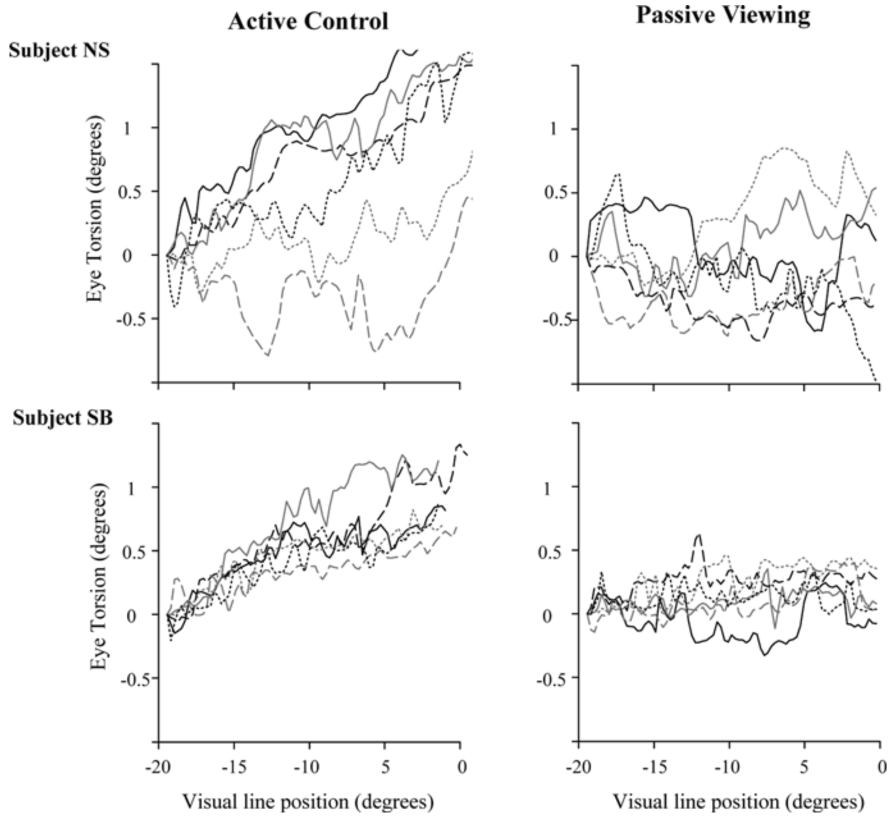

Fig. 1 Torsional eye positions for subjects NS and SB during Active (*right*) and Passive (*left*) line movements. All line rotations are in a clockwise direction towards the horizontal. Each trace represents an individual setting

regression lines were fitted to the torsional eye position as a function of stimulus position for each of these four components separately. The average of the four regression coefficients was labelled as the gain of entrainment for that trial, and that gain value formed the data on which the statistical analyses were performed. As Mezey et al. (2004) have shown that entrainment is conjugate in both eyes, only data from the dominant eye of each subject were used for the analysis.

Data were analysed as a within-subjects design to minimise the effect of the variability between subjects in their oculomotor responses (Mezey et al. 2004).

Results

Active versus Passive settings

Figure 1 shows representative torsional eye movement traces for two subjects in the Active and Passive conditions. The left column shows six Active settings made by the two subjects towards horizontal, where each line represents the torsional eye movement responses for one trial. The right column shows comparable data for Passive settings in the same subjects; in contrast with the Active settings, there is little or no entrainment. This result was evident in other subjects.

Collapsed over the direction of motion, the mean gain of entrainment was greater during the Active than during the Passive condition for five of the six subjects tested (Table 1). Although in one subject the result is not significant, his results still follow the same pattern.

Effort settings versus Passive settings

In five of six subjects, independent of whether it was a CW or CCW movement, Effort and Passive conditions were not statistically different (Table 2).

Across all levels of control over the stimulus movement, no subject had a significant difference between CW and CCW movements (all *P* values were greater than 0.05).

Figure 2 illustrates the consistency of the trend in entrainment between subjects. That is: (a) there is a consistently stronger torsional response to Active than to Passive movements; (b) the torsional gains during Passive and Effort conditions are generally similar for all subjects; (c) there are similar effects for both CW and CCW rotations.

Table 1 Summary of the mean and standard deviations of the regression coefficients. *F* and *P* values for the within-subject ANOVA comparing Active and Passive conditions are also included. In five of the six subjects, the gain of the optokinetic response is greater in the Active than in the Passive conditions

	Active		Passive		*F* value	*P* value
	Mean	SD	Mean	SD		
AB	0.095	0.0367	0.022	0.017	44.000	<0.005*
IC	0.021	0.0314	0.014	0.029	<0.005	1.000
SB	0.057	0.0202	−0.001	0.026	63.000	<0.005*
SG	0.169	0.0714	0.090	0.093	7.286	0.031*
JL	0.119	0.0587	0.039	0.050	18.789	0.003*
NS	0.200	0.0918	0.015	0.043	56.412	<0.005*
Mean	0.110	–	0.030	–	–	–

*Significant at the α=0.05 level

Table 2 Mean and standard deviations of the gain for Passive and Effort conditions independent of the direction of stimulus motion. *F* and *P* values for the within-subject ANOVA comparing Passive and Effort are also included. Five of the six subjects showed no statistical difference between Passive and Effort

	Passive		Effort		*F* value	*P* value
	Mean	SD	Mean	SD		
AB	0.022	0.017	0.004	0.019	7.000	0.033*
IC	0.014	0.029	0.012	0.030	<0.005	1.000
SB	−0.001	0.026	−0.004	0.021	<0.005	1.000
SG	0.090	0.093	0.108	0.048	0.677	0.438
JL	0.039	0.050	0.022	0.050	0.824	0.394
NS	0.015	0.043	0.010	0.022	<0.005	1.000
Mean	0.0298	–	0.0253	–	–	–

*Significant at the α=0.05 level

Discussion

The analysis showed that active control induced significantly greater entrainment of ocular torsion than passive viewing for the majority of subjects. Across subjects the average gain increased from 0.030 in the Passive conditions to 0.110 in the Active condition, an increase in gain by a factor of 2.7. In this study, unlike most other optokinetic studies, subjects were able to control the rotation of the visual stimulus, and this control is clearly an important factor in determining the torsional optokinetic response to a single line visual stimulus.

Mezey et al. (2004) investigated torsional responses to active and passive movements of the same visual stimulus in three subjects, but found that only one subject showed greater entrainment to active than to passive movements. Here we used more subjects, desaccaded data and an improved measure of gain (performing four linear regressions per trial rather than a single regression to all the data in a trial), and have shown a clear role for active control of the visual stimulus by the subject in determining the resultant optokinetic gain for this impoverished stimulus.

Differing levels of attention may explain the observed difference between active and passive movements. Subjects had to focus more on the rotation of the stimulus when they were controlling this rotation, and as previous research has found, the level of attention that subjects give to a stimulus may affect the resultant optokinetic response (Honrubia et al. 1968). Attention may possibly exert its effect on entrainment by affecting the sensation of circularvection (self-motion). A recent study showed that during the subjective sensation of circularvection, the slow-phase gain of torsional optokinetic nystagmus

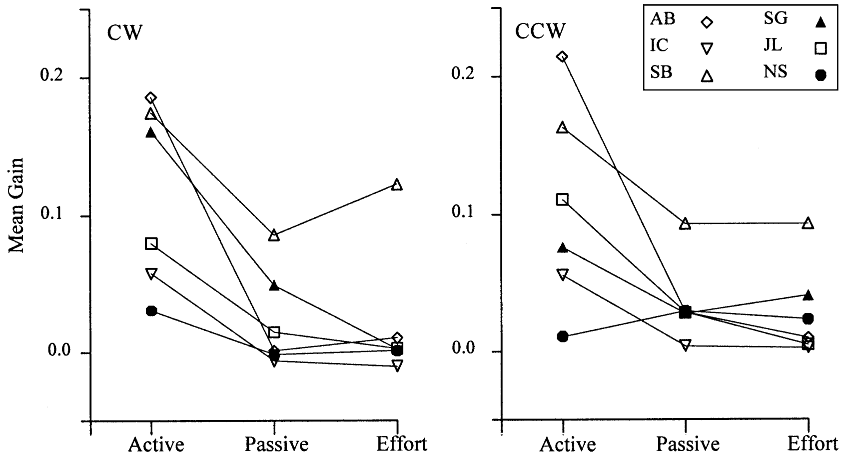

Fig. 2 Mean regression coefficient for each subject, for each stimulus condition. The overall pattern of results seen in the within-subjects analysis is consistent across subjects. That is: (a) there is greater entrainment in the Active conditions than in the Passive conditions; (b) the entrainment in the Passive and Effort condition is similar and generally very small. Each *symbol* represents a different subject, and the mean gain is the mean of all eight settings for that condition for that subject

(tOKN) increased in comparison with the tOKN measured during perceived object motion (Thilo et al. 1999).

The Effort condition was included to investigate whether the difference in torsional eye movement responses between active and passive movements was due to muscular effort involved in the task of holding down a mouse button in the Active condition. However, as there was no significant difference between the Effort and Passive condition, muscular effort cannot explain the difference in entrainment between Active and Passive movements.

Our results appear to be in conflict with the results of an earlier postural study (Guerraz et al. 2001) which showed that when subjects actively controlled or were cued to expect the horizontal movement of a very large (96° × 96°) visual display there was a reduced postural perturbation at the onset of the stimulus movement compared to trials when the same visual display moved unexpectedly. However, in that experiment giving the subject control or expectation of the onset and direction of the visual stimulus movement allowed for voluntary preparation and motor preprogramming for the forthcoming stimulus, so the reduced response in the ‘expectation’ conditions is to be expected. In our experiment the measured response, torsion, is generally held not to be under voluntary control so preparation and motor preprogramming would have been unlikely to be able to influence the torsional oculomotor response.

Most studies of optokinetic responses have used passive viewing of the moving stimulus. Our unexpected result raises the possibility that active control of the moving stimulus may affect other oculomotor responses and possibly perception, including for example in pilots. We and others (Wade and Curthoys 1997; Pavlou et al. 2003) have shown that the perception of the roll orientation of a visual stimulus is significantly affected by the torsional position of the eye and our present result shows that active control of the visual stimulus affects the torsional position of the eye and so active control may affect perception of roll orientation of visual stimuli.

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