Saccades horizontal or vertical at near or at far do not deteriorate postural control

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Received 5 March 2007; accepted 12 July 2007

Abstract

Objective: There is a discrepancy about the effect of saccades on postural control: some studies reported a stabilization effect, other studies the opposite. Perturbation of posture by saccades could be related to loss of vision during saccades (saccades suppression) due to high velocity retinal slip. On the other hand, efferent and afferent proprioceptive signals related to saccades can be used for obtaining spatial stability over saccades and maintaining good postural control. In natural conditions saccades can be horizontal, vertical and made at different distance. The present study examines all these parameters to provide a more complete view on the role of saccade on postural control in quiet stance.

Methods: Horizontal or vertical saccades of 30° were made at 1 Hz and at two distances, 40 and 200 cm. Eye movements were recorded with video-oculography (EyeLink II). Posturography was recorded with the TechnoConcept platform. The results from “saccade” conditions are compared to “fixation control” condition (at far and near).

Results: The video oculography results show that subjects performed the fixation or the saccade task correctly. Execution of saccades (horizontal or vertical at near or at far distance) had no significant effect on the surface of center of pressure (CoP), neither on the standard deviation of the lateral body sway, nor on the variance of speed of the CoP. Moreover, whatever the distance, execution of saccades decreased significantly the standard deviation of the antero-posterior sway.

Conclusion: We conclude that saccades, of either the direction and at either the distance, do not deteriorate postural control; rather they could reduce sway. Efferent and proprioceptive oculomotor signals as well as attention could contribute to maintain or improve postural stability while making saccades.

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Keywords: Postural control; Fixation; Horizontal saccades; Vertical saccades; Distance

1. Introduction

Postural control is a complex multi-sensory system using visual, vestibular, somatosensory and proprioceptive inputs. The majority of postural studies are done with subjects asked to fixate a target. The role of eye movement on postural stability is less studied. There is a variety of different types of eye movements; each stimulated by different input and each serving vision in a different way. For instance, saccades and pursuit movements are stimulated by position and velocity visual error signals, respectively. The saccade brings the objects of interest at the fovea while the pursuit keeps the moving object on the fovea.

Here we will concentrate on studies of saccades. Saccade is a fast stereotyped movement. Their velocity can be high, e.g. 500°/s or more in humans [1]. During the saccade, perception and visual analysis are quasi impossible, the so-called saccade suppression presumably due to high velocity of retinal slip.

High velocity retinal slip and suppression of vision produced by the saccade could theoretically deteriorate postural stabilization. However, earlier studies found that saccades either do not disrupt [2] or decrease body sway [3–5]. White et al. [2] used 4° horizontal saccades triggered
by two light targets lighted on sequentially. Uchida et al. [5] studied the effect of periodic saccades on postural sway. Eye movements were recorded with electro-oculography. Saccades were induced by asking subjects to re-fixate LED targets placed horizontally or vertically. Saccade sizes studied were 5–40° and the frequency of saccades was 0.1–1 Hz. During such periodic saccades the authors reported decrease of body sway, i.e., an improvement of postural control. They concluded that repetitive activation of eye muscle proprioceptors does not destabilize posture. Indeed internal information relative to the execution of the saccades could contribute in such stabilization of the posture. In normal subjects a subsequent study from Kikukawa and Taguchi [4] also demonstrated that saccadic eye movement induced by target moving stepwise decreased body sway. The group that has examined most extensively the role of eye movement on postural control is the group of Brandt. In their earlier studies [6,7], horizontal saccades (5–80°) with frequency of 0.5 Hz were studied; such saccades deteriorated postural stabilization relative to fixation condition. The deterioration was higher for the larger saccades. The findings of Brandt are in contradiction with those of earlier studies mentioned above. Finally, a recent study of Stoffregen et al. [8] found that medio-lateral sway of torso displacement and of head motion decreased during horizontal saccades. The stimuli used were two circles alternating on computer screen (11° of amplitude and 0.583 Hz of frequency).

Another aspect influencing the postural stability is the viewing distance. Postural stability is better at near distance than at far. The traditional interpretation of this phenomenon is in terms of angular size of retinal slip: at near distance the angular size of retinal slip input resulting from body sway is higher than at far distance and could explain better body stabilization than the far distance [6,9–11]. Kapoula and Lê [12] confirmed the distance effect in young and elderly. Moreover, they showed that the ocular convergence at near distance could be also important. Indeed, in their study they use convergent prisms that lead the eyes to converge while the subjects were fixating at far distance. Convergence of the eyes improved postural stability.

The aim of the present study is to provide a complete view of the role of saccades on postural control by examine saccades for both horizontal and vertical directions and at far and near distances.

2. Materials and methods

2.1. Subjects

Eleven subjects, age range from 22 to 29 years (mean age 25.5 ± 2.5 years), were recruited among the laboratory co-workers. Medical examination and several preliminary tests confirmed normal findings without neurological signs, and no medication. The investigation adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional human experimentation committee. Informed consent was obtained from all subjects after the nature of the procedure had been explained.

2.2. Platform

To measure the postural stability, we used a posturography apparatus consisted by two dynamometric platforms; one for each foot (produced by TechnoConcept, Céreste, France). The excursions of the center of pressure (CoP) were measured during 51.2 s; the equipment contained an Analogue-Digital converter of 16 bit. The sampling frequency of the CoP was 40 Hz.

2.3. Eye movement recording

Eye movements were recorded with the Eyelink II. This video system was set to acquire eye position at 250 Hz. The apparatus is consisted of video cameras that are mounted on helmet. The cable of the helmet was placed upon a special support so that the total weight and traction force of the cable was kept minimal (see Fig. 1). The visual field when wearing the EyeLink apparatus is completely free as the video cameras are placed below the line of sight. Fig. 1 shows the arrangement used; the subjects stood on the platform wearing the EyeLink apparatus. He (she) stood in front of a screen, upon which five targets were presented at 0° and at 15° up, down, left, right; the screen was either at 40 cm or at 200 cm from the subjects.

2.4. Visual target

The targets were a cross “×” placed between two vertical segments. The angular size of the cross × was adjusted to subtend 1° for both viewing distances (200 and 40 cm). The same targets were used for the calibration.

2.5. Oculomotor and posturography procedure

Quiet stance posturography was done in a normally furnished experimental room. Subjects were placed on the platform. At the beginning of the session, a metronome was placed on the back of the screen producing a sound at 1 Hz. The subject stood upright on the platform (arms side by side along the body). The experiment started with calibration session during which the subject was asked to make saccade on the pace of the metronome (1 Hz) between the center-up, center-down, center-left and center-right targets. The eye movement calibration sequence was repeated twice.

Next the posturography was triggered for a period of 51.2 s. For each postural measure subjects were asked to make either horizontal saccades from the left to the right target or vertical saccades from the down to the upper target at 1 Hz. The amplitude of the saccades was 30°, both for the
horizontal and vertical direction. The frequency used (1 Hz) has been used by others [5]. In the control condition, subjects were asked to fixate the target on the center of the screen. Importantly, the metronome was always on beating at 1 Hz. For all conditions and in parallel with posturography eye positions data were recorded continuously.

All three conditions (fixation, horizontal saccade, vertical saccade) were conducted twice; once at near distance (40 cm) and the other at 200 cm. The order of the viewing distances were counterbalanced as nearly as possible between the subjects and for each distance the order of the viewing conditions (fixation, horizontal saccade, vertical saccade) was also counterbalanced as nearly as possible.

2.6. Postural measures

We analysed the surface of the CoP excursions, the standard deviations of anterio-posterior (SDy) and lateral body sways (SDx) and the variance of speed. The surface of CoP was calculated so that 90% of the instantaneous positions of the CoP were inside an ellipsoid [13]. Note that many recent studies use standard deviation of CoP [14,15].

2.7. Eye movement measures

After calibration we calculated the conjugate eye position that corresponds to the left plus right eye position divided by two. We also measured the vergence angle that is the difference between left minus right eye; the vergence angle was measured during fixation or during the execution of saccades for all conditions. Eye movement recording were done for all subjects but for two of them calibration problems occurred and the results were not usable; only posturography data from the two subjects were available.

2.8. Statistical analysis

For eye movement data, we measured the mean amplitude and the standard deviation of the saccades, the frequency of corrective saccades and the vergence angle for each viewing distance.

For posturography parameters, a two way ANOVA was run with two factors: the distance and the type of eye movement with three levels: fixation, horizontal and vertical saccades. Post hoc analysis was made with the Fischer’ LSD test.

3. Results

3.1. Eye movements

Fig. 2 shows traces of conjugate eye position in the three tasks (fixation, horizontal and vertical saccades) at far or at near distances. As the oculomotor behaviour of saccades and fixation was very stereotyped we averaged traces from nine subjects together. To average traces we excluded the first three saccades as the initiation of the first saccades could occur with a different latency for different subjects. During the fixation task the eyes are almost perfectly stable regardless of the distance. During the saccade tasks subjects performed saccades at the required pace (1 Hz).

Group means of saccade amplitudes are shown in Table 1. The mean amplitudes of saccades were similar for both horizontal and vertical directions. The frequency of corrective saccades was similar for the two directions; the vergence angle was close to the requirement vergence (i.e. 9° at 40 cm and 2° at 200 cm). Thus, the eye movement results confirm that the subjects were performing correctly in the saccade tasks and in the fixation task they were fixating in a stable way.
3.2. Posture measures

The group mean values of posturography parameters (surface of CoP, the standard deviation of lateral (SDx) and antero-posterior sway (SDy) of the variance of speed) are shown in Table 2 for each distance and for each viewing condition. Next we will present the results of ANOVA evaluating the effects of distance and of viewing conditions on each of the postural parameters.

3.2.1. Distance

There was a main effect of distance on the surface of CoP ($F_{(1,10)} = 7.5, p = .021$), on the SDx ($F_{(1,10)} = 5.8, p = .036$) and on the variance of speed ($F_{(1,10)} = 8.2, p = .017$). For these three parameters, values were significantly higher at far distance than at near. These results are consistent with prior studies [9–12,16] and show that the postural stability is better at near distance than at far distance.

3.2.2. Eye movement conditions: fixation versus saccades

Eye movement condition had no main effect on the surface of CoP, the SDx or on the variance of speed. The only significant effect of the viewing condition is on the standard deviation on the antero-posterior (SDy) body sway ($F_{(2,20)} = 5.2, p = .015$). This effect is illustrated in Fig. 3.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>40 cm fixation</th>
<th>200 cm fixation</th>
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<tr>
<td></td>
<td>Horizontal saccades</td>
<td>Vertical saccades</td>
</tr>
<tr>
<td>Mean amplitude (°)</td>
<td>30.27 ± 0.74</td>
<td>29.9 ± 1.83</td>
</tr>
<tr>
<td>Corrective saccade frequency (%)</td>
<td>31.71</td>
<td>35.4</td>
</tr>
<tr>
<td>Vvergence angle (°)</td>
<td>8.31 ± 1.07</td>
<td>1.67 ± 0.89</td>
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Mean ± S.D. for saccades (horizontal and vertical) and for vergence angle and corrective saccades frequency.
As shown, the SDy was higher when subjects were fixating than when they were making horizontal saccades \((p = .013)\), or vertical saccades \((p = .0092)\). There was no significant difference between horizontal saccades versus vertical saccades for the SDy.

### 3.2.3. Frequency

One could ask whether making saccades at 1 Hz would also influence the 1 Hz component of the body sway. The amplitudes of the 1 Hz component from Fast Fourier Transform of the lateral (FFT\(_x\)) and the antero-posterior (FFT\(_y\)) sway were analysed; a two way ANOVA was applied on the values of amplitude of 1 Hz component. The two factors were the distance (40 and 200 cm) and the eye movement condition (fixation, horizontal and vertical saccade). For both the FFT\(_x\) and the FFT\(_y\), there was no significant effect neither of the distance \((F_{(1,10)} = .56, p = .47\) and \(F_{(1,10)} = 4.39, p = .0624\) respectively), nor of the eye movement condition \((F_{(1,10)} = .84, p = .44\) and \(F_{(1,10)} = 2.96, p = .0745\), respectively); and there was no interaction between distance and eye movement condition \((F_{(2,20)} = 1.76, p = .197)\) and \(F_{(2,20)} = 2.37, p = .119\), respectively).

### 4. Discussion

This study brings straightforward results: execution of saccades, being horizontal or vertical made at far or at near distance does not deteriorate postural control. On the contrary, there is evidence for mild improvement of postural stabilization in terms of reduction antero-posterior body sway. Our findings are in line with those from prior studies from Uchida et al. [5] and Kikukawa and Taguchi [4] and contradict those from Brandt et al. [7]. Importantly, our findings provide more complete view as they concern both horizontal and vertical saccades at far and near distances. Note that the majority of studies show no deterioration of postural stability of the saccades [2–5,8] despite of the difference of visual stimuli, frequency of saccades, and eccentricity of targets used. Thus, taken together our findings with those from earlier studies, one could conclude for undisturbance of postural control by execution of saccades at any distance and direction. The distance dimension is of importance as in natural conditions we continuously change the distance at which we make saccades. Also at near distance the retinal slip caused by the saccades is of higher angular size and could be theoretically more disturbing but it is not.

Therefore the question to ask is by which physiological mechanisms the central nervous system achieves this result, i.e. maintenance or improvement of postural control despite of brusque and rapid saccadic eye movement.

As mentioned in the Introduction, the rationale for expecting destabilization during saccades is related to suppression of vision and perception because of high velocity retinal slip produced by the saccade. Postural stabilization is believed to be better with vision than without. This result shows that brusque saccades causing short duration of suppression do not deteriorate postural stabilization. Most likely ocular motor signals such as corollary discharge or efferent motor signals contribute to stable vision across the saccades. Sommer and Wurtz [17–
head–neck and postural control. Corneil et al. [21] showed that neck muscles are recruited time-locked to visual target presentation; usually well in advance of saccadic eye movements. Thus the oculomotor circuitry and the head-neck circuitry are interconnected with redundant internal efferent and afferent signals; these signals are presumably used together to assure postural stabilization with or without saccades. Proprioception from the extraocular muscles is among the richest proprioceptive sources in human motor effectors (see [22]) and could play a major role on the stabilization of the body. According to this interpretation, execution of saccades in complete darkness should be also harmless for posture stability. Further studies in dark are in progress in our laboratory.

Finally, one should discuss the result of improvement of antero-posterior sway when the subject made horizontal or vertical saccades relative to fixation condition. This observation is in line with prior studies reporting reduction of postural sway (see Kikukawa and Taguchi [4] and Uchida et al. [5]). This improvement is attributed to increased proprioceptive and efferent oculomotor signals. As in our study no improvement was found for the surface and the lateral sway thus the result for reduced antero-posterior sway should be taken with caution. A possible reason for which execution of saccades improves especially the antero-posterior body sway is the following: unwanted antero-posterior sway would directly modify the angular size of targets; execution of such accurate saccades between the targets prevented or reduced small natural antero-posterior sway.

Yet, it should be recalled that eye movements are tightly linked to shifts of visual attention (see for instance premotor theory of visual attention [23]). Perhaps making saccades regularly implies higher attention control, thereby a tighter mode of regulation of postural oscillations. In another study we found postural control to be less efficient for dyslexic than for non-dyslexic children but only during execution of saccades in complete darkness should be also harmless for posture stability. Further studies in dark are in progress in our laboratory.

We conclude that execution of saccades (horizontal and vertical) at near or at far, do not interfere with quality of posture stabilization. On the contrary, they can improve some aspects, e.g. reduce antero-posterior sway. Efferent proprioceptive signals from extra-ocular muscles and/or attention shifts could be at the origin of maintenance or improvement of posture control when execution saccades.

Acknowledgements

The authors thank Q. Yang for helping with eye movement analysis; T. Eggert for providing the software for eye movement analysis. T.T. Lê was supported by European Union (QLK6-CT-2002-00151: EUROKINESIS) and CNRS/CTI, Handicap contract.

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Please cite this article in press as: Rey F, et al., Saccades horizontal or vertical at near or at far do not deteriorate postural control, Auris Nasus Larynx (2007) xxx–xxx.


