Supramodal effects of galvanic vestibular stimulation on the subjective vertical.
Franck Mars, Konstantin Popov, Jean-Louis Vercher

To cite this version:
Franck Mars, Konstantin Popov, Jean-Louis Vercher. Supramodal effects of galvanic vestibular stimulation on the subjective vertical.. NeuroReport, 2001, 12 (13), pp.2991-4. hal-00394768

HAL Id: hal-00394768
https://hal.science/hal-00394768
Submitted on 5 May 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Supramodal effects of galvanic vestibular stimulation on the subjective vertical

Franck Mars, CA Konstantin Popov1 and Jean-Louis Vercher

FRE 2099, Mouvement and Perception, CNRS and Université de la Méditerranée, Faculté des Sciences du Sport, CP 910, 163, avenue de Luminy, F-13288 Marseille Cedex 9, France; 1Institute for Information Transmission Problems Russian Academy of Sciences, 19 Bolshoi Karetnyi per., 101447 Moscow GSP-4, Russia

CA Corresponding Author

Received 9 July 2001; accepted 20 July 2001

This study investigated whether the tilt of the subjective vertical induced by galvanic vestibular stimulation, demonstrated by asking subjects to set a rod to the vertical, was specific to the visual modality or could be found in two tasks relying on proprioceptive and somatosensory cues. In all cases, settings were significantly deviated in the direction of the anode, but errors were smaller in the somatosensory tasks than in the visual task. We propose that the effects observed in the somatosensory modality reflect only a modification of the central representation of gravity, whereas visual effects are also in part the consequence of unregistered ocular torsion. NeuroReport 12:1–4 © 2001 Lippincott Williams & Wilkins.

Key words: Gravity; Ocular torsion; Proprioception; Reference frame; Spatial orientation; Vision

INTRODUCTION

Information provided by the vestibular system has been extensively studied for its fundamental role in the neural coding of space [1,2]. One recurrent problem with some methods classically used to stimulate the vestibular system, like head tilt, body tilt or alteration of the gravito-inertial field, resides in the fact that they generate concurrent proprioceptive and somatosensory signals. On the other hand, galvanic vestibular stimulation (GVS) has the particular advantage of selectively activating the vestibular system. This technique consists of applying moderate direct current between the mastoid processes which modulates the spontaneous firing of vestibular nerve fibers: increased frequency on the cathode side and decreased frequency on the anode side [3]. Effects of GVS have been demonstrated on various sensorimotor functions, such as the control of eye movements [4,5], posture [6,7] and walking [8,9].

Recently, several studies have focused on the effects of GVS at the perceptual level. The perception of verticality was asked subjects to reproduce the subjective tilt of the visual scene experienced during GVS [10,11] or to set a visual line to the vertical [12]. Subjects perceived the visual scene as tilted in the direction opposite to anodal stimulation. As a consequence, when instructed to indicate the visual vertical, subjects committed an error toward the anode. In addition to the perceived tilt of the visual scene, Zink et al. [10,11] recorded static torsion of the eyes induced by the same stimulation. Perceptual and oculomotor effects were in the same direction and both were linearly correlated with stimulus intensity, with ocular torsion being of only slightly smaller amplitude than the tilt of the visual vertical. It is tempting to wonder whether the tilt of the visual vertical is the consequence of the unregistered torsion of the eyes or not. This hypothesis is supported by the work of Wade and Curthoys [13], who investigated the relationship between ocular torsion and perceptual tilt of the visual horizontal produced during whole-body tilt. The authors compared two methods of measuring the perceived horizontal, one involving a visual line, the other involving proprioceptive and somatosensory cues, i.e. adjusting a solid rod with the hands in darkness. They observed an effect of tilting the body in the visual modality, but not in the somatosensory modality. Besides, tilt of the visual line and ocular torsion strongly correlated. Wade and Curthoys [13] concluded that the difference between the visual and somatosensory settings was primarily due to the change in ocular torsional position, contradicting previous models which stressed the role of central processing in the genesis of the effects [14].

The aim of the present study was to investigate, in a within-subject design, whether the tilt of the subjective vertical induced by GVS is specific to the visual modality. For this, we compared vertical settings performed by remotely controlling the orientation of a visual rod (visual task) with those performed by holding with one hand a light wooden rod in darkness (somatosensory task). If perceptual effects of GVS were exclusively due to ocular torsion, subjects holding a solid rod to the perceived vertical should not be influenced by the stimulation. On the contrary, somatosensory settings deviated in the direction of anodal stimulation would suggest a change of the central representation of gravity. Whatever the case, any difference observed between the visual and somatosensory
tasks could be attributed to visuovestibular effects, with unregistered ocular torsion as a candidate.

A second point of the experiment was to compare two methods of indicating the vertical in the somatosensory modality. Both tasks were quite similar and consisted of adjusting the same wooden rod with one hand to the perceived vertical, but, in one condition, the rod rotated around an axis mounted on an earth-fixed support, whereas, in the other condition, the subjects held the detached rod in front of them. An anchor in space such as the one provided by the earth-fixed device has been showed to influence vestibular-driven illusions. For instance, illusions of torso rotation induced by sinusoidally rotating the head of a stationary subject can be suppressed if the subject is allowed to grasp a spatially fixed handle [15]. Thus, we hypothesized that a space-referenced anchor could prevent a potential tilt of the subjective vertical from occurring in the somatosensory modality.

MATERIALS AND METHODS

Fourteen subjects (three women and 11 men, aged 21–53 years) were included in the study, which was approved by the local ethics committee. The subjects gave their informed consent after being briefed about the experiment. All were free of known vestibular or neurological problems and had normal or near-to-normal vision. Subjects were seated in a chair. Their head was kept in alignment with the trunk by a neck brace. A headrest supported the back of the head and a strap pressed on the forehead to keep the head in a fixed position during the experiment. This method prevented any postural tilt of the trunk or of the head usually associated to GVS.

Two homemade stimulating electrodes consisting of plastic cups (diameter 3 cm), filled with pieces of cloth, were kept in place binaurally over the mastoid bones by an extensible rubber headband. The pieces of cloth were saturated with salted water to ensure proper conduction between the skin and the electrodes. The stimuli were computer-controlled and delivered via a battery-powered constant current stimulator. A progressive increase of stimulus intensity was chosen because they are known to produce unpleasantness associated to the abrupt onset of a pulse stimulation [4,11]. Thus, we hypothesized that a space-referenced anchor could prevent a potential tilt of the subjective vertical from occurring in the somatosensory modality.

Control trials were performed without stimulation. The course of one trial is illustrated in Fig. 1. If subjects declared that they were not satisfied with their performance, the trial was run again at the end of the session. The experiment was divided into three sessions, conducted on separate days. One experimental session lasted about 1 hour and consisted of 25 trials, which corresponded to five different stimuli (two anodal stimulations on the left, one control without stimulation, two anodal stimulations on the right), repeated five times. The order of presentation of the stimuli was randomized. Rest periods of 30 s were inserted between consecutive trials.

The Three experimental sessions differed by their methods of assessing verticality. The order of presentation was counterbalanced. In the visual condition (VSL), a computer-generated sounds that punctuated the trial. S1 signaled the beginning of the trial. S2 and S3 respectively defined the beginning and the end of the response period when subjects opened their eyes, whatever the condition (even if it did not involve vision) and set the rod to the vertical. S4 signaled the end of the stimulation and the beginning of the rest period.

RESULTS

Figure 2 summarizes the averaged data obtained in the experiment. It shows that GVS always resulted in a devia-
stimulation were respectively assigned anodal stimulation and errors in the direction of cathodal committed with GVS (Fig. 2b). Errors in the direction of condition (no stimulation) was subtracted from the errors statistical analyses, the error committed in the control tion of vertical settings toward the anode, relative to the reference values obtained in the control conditions. For statistical analyses, the error committed in the control condition (no stimulation) was subtracted from the errors committed with GVS (Fig. 2b). Errors in the direction of anodal stimulation and errors in the direction of cathodal stimulation were respectively assigned positive and negative values. A 2 (1.25 mA/2.5 mA) × 2 (anode on the right/anode on the left) × 3 (VSL/UNS/ANS) repeated-measures ANOVA performed on these data revealed a significant effect of stimulus intensity (F(1,13) = 6.28, p < 0.05), no effect of the side of the anode (F(1,13) = 0.04), and a main effect of response modality (F(2,26) = 6.22, p < 0.01). There was no significant interaction. Contrast analyses tested whether vertical settings were deviated in the direction of the anode in each modality. The effect was significant in VSL (F(1,13) = 17.06, p < 0.01), UNS (F(1,13) = 39.27, p < 0.001) and ANS (F(1,13) = 7.89, p < 0.05). In addition, Newman–Keul’s tests indicated that errors committed in VSL were significantly larger than in UNS (p < 0.05) and in ANS (p < 0.01). Both somatosensory response modalities did not differ on average. However, correlational analyses revealed some differences between the two somatosensory tasks (Table 1). Indeed, the performance in ANS and UNS did not correlate (r = 0.20). Moreover, whereas UNS tended to positively correlate with its visual counterpart, even if both sets of data failed to significantly correlate (r = 0.47, p < 0.10), ANS did not correlate at all with VSL (r = 0.06).

**DISCUSSION**

As reported in previous studies [10–12], GVS yielded a tilt of the visual vertical toward the anode. It was also demonstrated for the first time that this effect was not specific to the visual modality: it could also be observed when subjects had to set to the vertical a solid rod held with one hand in darkness, a task relying on proprioceptive and somatosensory information. The effect was smaller when vision was excluded, but remained very consistent, especially when the display did not provide an earth-fixed reference. Both somatosensory tasks did not differ on average when they were used to assess the subjective vertical. However, when the device was not anchored to a earth-fixed support, the effect of GVS was more consistent. This could be predicted, as a stable anchor in space has been demonstrated to suppress vestibular-driven illusions [15] and to increase postural stability [16].

GVS produced large interindividual variability in the magnitude of the effects on the subjective vertical, as already reported in previous studies, and some subjects were differently affected by the stimulation in function of the task. In spite of this variability and of the reduced pool of tested subjects, the fact that visual and unanchored somatosensory settings tended to correlate suggests that both effects share, at least partially, some common processes. We propose that the effects observed in the somatosensory modality reflect a modification of the central representation of gravity. This hypothesis is supported by neurophysiological studies using functional magnetic resonance imaging [17,18]. GVS activated cortical areas related to oculomotor control and vestibular functions, but also

<table>
<thead>
<tr>
<th>Subject</th>
<th>Visual</th>
<th>Unanchored somatosensory</th>
<th>Anchored somatosensory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.52</td>
<td>0.95</td>
<td>0.83</td>
</tr>
<tr>
<td>2</td>
<td>3.43</td>
<td>0.96</td>
<td>0.11</td>
</tr>
<tr>
<td>3</td>
<td>2.54</td>
<td>0.86</td>
<td>−0.24</td>
</tr>
<tr>
<td>4</td>
<td>1.67</td>
<td>0.66</td>
<td>0.81</td>
</tr>
<tr>
<td>5</td>
<td>1.51</td>
<td>0.25</td>
<td>0.03</td>
</tr>
<tr>
<td>6</td>
<td>1.25</td>
<td>0.18</td>
<td>0.93</td>
</tr>
<tr>
<td>7</td>
<td>1.08</td>
<td>0.42</td>
<td>−0.25</td>
</tr>
<tr>
<td>8</td>
<td>0.98</td>
<td>1.29</td>
<td>−0.04</td>
</tr>
<tr>
<td>9</td>
<td>0.66</td>
<td>0.16</td>
<td>0.46</td>
</tr>
<tr>
<td>10</td>
<td>0.66</td>
<td>0.97</td>
<td>0.02</td>
</tr>
<tr>
<td>11</td>
<td>0.63</td>
<td>0.66</td>
<td>0.53</td>
</tr>
<tr>
<td>12</td>
<td>0.59</td>
<td>0.64</td>
<td>0.96</td>
</tr>
<tr>
<td>13</td>
<td>0.43</td>
<td>0.45</td>
<td>1.40</td>
</tr>
<tr>
<td>14</td>
<td>−0.18</td>
<td>0.11</td>
<td>−0.44</td>
</tr>
<tr>
<td>Mean</td>
<td>1.41</td>
<td>0.61</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Data are ordered in function of the magnitude of the effects obtained in the visual condition. Bold values signal conditions in which no effect of GVS could be described.
multisensory areas, such as the inferior parietal lobule, which is involved in the building of internal reference frames.

In Zink et al. [11], a GVS of 2.5 mA induced a tilt of the subjective vertical which was on average 0.7° larger than the amount of ocular torsion. Interestingly, the effect observed in the present study on somatosensory settings is about the same magnitude. This could suggest that the effects observed in the visual modality would be the consequence of a tilt of the central representation of gravity in addition to ocular torsion. This hypothesis would imply that galvanically-induced ocular torsion is not taken into account by the perceptual system (either via efference copy or proprioception of the eye muscles) in making visual judgments of orientation, as has already been proposed [19,20]. However, some conflicting results exist. Indeed, Nakayama and Balliet [21] and more recently Haustein and Mittelstaedt [22] studied the relation between the visual vertical and eye torsion induced by oblique position of gaze, according to Listing’s law. They concluded that, although the vertical judgments were not peridical, they did not conform to a retinotopic prediction. Thus, an extra-retinal signal, probably derived from the efference copy of gaze direction command, would allow compensating in part for ocular torsion. Whether or not the difference between visual and somatosensory settings reported here corresponds to the amount of ocular torsion remains to be determined. Watson et al. [4], who recorded ocular torsion during maintained GVS as in the present study, gave credence to this hypothesis. They observed that a GVS of 3 mA produced some tonic torsion of about 0.8°, that is in the order of the difference between visual and somatosensory settings at 2.5 mA. A replication of the present study with recorded ocular torsion would certainly clarify this point.

CONCLUSION

This study demonstrated for the first time that the influence of GVS on the subjective vertical could also be found when vision is excluded. In that case, the biased perception of the vertical direction was most probably the consequence of a tilt of the gravitational reference frame, produced by asymmetric vestibular stimulation in the absence of head tilt. When estimating the subjective vertical in the visual modality, additional effects linked to lower-level visuo-vestibular interactions came into play.

REFERENCES


Acknowledgments: This work was supported by grants from CNRS FRE 2099 and Dassault Aviation. K.P. was supported as an invited researcher by the Centre National de la Recherche Scientifique (CNRS).