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Body tilt effects on the visual reproduction of orientations and the Class 2 oblique effect (E. A. Essock, 1980) were examined. Body tilts indicate whether the oblique effect (i.e., lower performance in oblique orientations than in vertical–horizontal orientations) is defined in an egocentric or a gravitational reference frame. Results showed that the oblique effect observed in upright posture disappeared in tilted conditions, mainly due to a decrease in the precision of the vertical and horizontal settings. In tilted conditions, the subjective visual vertical proved to be the orientation reproduced the most precisely. Thus, the oblique effect seemed to be not purely gravitationally or egocentrically defined but, rather, to depend on a subjective gravitational reference frame tilted in the same direction as body tilts.

It is well documented that orientation processing is anisotropic; the vertical and horizontal orientations are perceived more precisely than the oblique orientations. The origin of this phenomenon, called the oblique effect by Appelle (1972), is still debated. In vision, the multiplicity of cortical structures involved in visual orientation processing raises the question about the anatomofunctional level contributing specifically to the visual oblique effect. Still unknown is whether the visual oblique effect takes root in low levels of the visual system, in higher levels, or both (for a recent review, see Gentaz & Ballaz, 2000). Some studies have suggested that this anisotropy in perceptual performances could be explained by the axis-dependent change in the properties of orientation-selective neurons of the visual primary cortex (Banks & Stolantz, 1975; Chen & Levi, 1996; Corwin, Moskowitz-Cook, & Green, 1977; Furmanski & Engel, 2000; Lennie, 1974; Orban, Vandenbussche, & Vogels, 1984; Saarinen & Levi, 1995), because the neurons that are tuned to horizontal and vertical orientations are more numerous, sensitive, and narrowly tuned than the neurons that are tuned to oblique orientations. By contrast, other studies have led researchers to conclude that the origin of the visual oblique effect could be more central, implying that additional extraretinal cues such as vestibular and somesthetic ones are integrated at a higher level in the visual hierarchy, probably at or beyond the locus of orientation constancy (Attneave & Olson, 1967; Buchanan-Smith & Heeley, 1993; Ferrante, Gerbino, & Rock, 1995; Lipshits & McIntyre, 1999).

Essock (1980) has proposed a distinction between Class 1 oblique effects, observed when one is measuring the basic functioning of the visual system (acuity, contrast threshold), and Class 2 oblique effects, observed in paradigms enhancing cognitive processes (identifying, remembering, or categorizing the orientations of stimuli). Class 1 effects can be consistently explained by properties of orientation-selective neurons. The origin of Class 2 oblique effects is less clear. In Essock’s (Essock, 1980; Essock, Krebs, & Prather, 1997) research, the Class 2 oblique effects could be explained by a general bias in the representation of an oblique stimulus. This bias could stem from the fact that any oblique orientation could be encoded in relation to the vertical and horizontal norms that define a reference frame, whereas the vertical and horizontal orientations would be encoded directly (Foster & Westland, 1998; Gentaz, 2000; Gentaz & Hatwell, 1996; Gentaz, Luyat, Cian, Hatwell, Barraud, & Raphael, 2001; Regan & Price, 1986). From this perspective, identifying the nature of the spatial reference frame in which the orientations are mapped would allow a better understanding of the origin of the Class 2 visual oblique effect.

Different reference frames can be selected to define a visual orientation in space. A classical broad distinction is made between egocentric (referred to the observer’s body) and allocentric (referred to environmental cues) spatial frames (for reviews, see Berthoz, 1991; Howard, 1982; Rock, 1990; N. J. Wade, 1992). Several egocentric reference frames can be defined: (a) a retinocentric reference frame, (b) a head- or trunk-centered reference frame, and (c) a hand–shoulder-centered reference frame if the observer has to simultaneously adjust the visual stimulus with his or her hand. The allocentric reference frames can be divided into a gravitational frame defined by the direction of the gravity pull (geocentric frame) and a pattern-centric reference frame defined by visual contextual cues. In usual experimental conditions, the gravitational, body-centered, and visual reference frames are often aligned. Consequently, the oblique effect could result from either...
egocentric or allocentric mapping of orientations. However, in the absence of visual contextual cues, tilting the body uncouples the gravitational and egocentric reference frames and then permits specification of the reference frame in which orientations are defined. If the visual oblique effect is mapped in a retinotopic reference frame, its origin could be located at a low level of visual processing where the retinotopical mapping of most orientation-selective neurons is preserved. By contrast, if the visual oblique effect is defined in a body-egocentric or a gravitational reference frame, its origin could be located at a high level of the visual processing of orientation.

The effect of tilt postures on the visual oblique effect has been investigated with different tasks such as visual search (DeFord, Prather, & Essock, 1998, 1999), relative looking times on oblique and vertical patterns (Jouen, 1985), orientation-discrimination tasks (Attneave & Olson, 1967; Buchanan-Smith & Heeley, 1993; Chen & Levi, 1996; Ferrante et al., 1995; Orban et al., 1984), contrast sensitivity tests (Banks & Stoluart, 1975; Lennie, 1974), vernier acuity paradigms (Corwin, Moskowitz-Cook, & Green, 1977; Saarinen & Levi, 1995), and reproduction tasks (Lipshtis & McIntyre, 1999). However, as noted by Essock (1980), the nature of the paradigm used can favor a particular spatial frame. The Class 1 oblique effects would be tied to retinal coordinates reflecting the basic functioning of the visual system, whereas the Class 2 oblique effects could be defined in another reference frame, such as the gravitational reference frame. However, it is possible that on a certain task, more than one anisotropy (low-level sensory anisotropy and encoding-memory anisotropy) can sometimes contribute to the observed perceptual performances (Essock et al., 1997). Thus, the effect of tilt postures should be examined in studies using similar paradigms.

Using an orientation-discrimination task (Class 2 oblique effect), Attneave and Olson (1967) showed that the faster time of detection for vertical and horizontal stimuli relative to oblique ones remained in the 45° head-tilted condition. These results were in favor of gravitational coordinates underlying the visual oblique effect. With a similar orientation-discrimination task, Buchanan-Smith and Heeley (1993) found also that the lowest thresholds of detection were those corresponding to orientations aligned with the gravitational vertical and horizontal, whatever the position of the head (vertical or tilted 45°). From the same perspective, Ferrante et al. (1995) found that the Goldmeier effect—the fact that a right angle is perceived as such only when its sides are positioned at the vertical and horizontal—could be explained by gravitational coordinates: The right angle’s sides must be positioned to the gravitational vertical and horizontal.

By contrast, findings from other studies with similar paradigms have instead supported a retinotopic frame of reference (Chen & Levi, 1996; Orban et al., 1984). Chen and Levi tested the effects of body tilts on orientation discrimination of two parallel and two perpendicular lines in the presence of a simultaneous spatial reference (the second line). The thresholds for discrimination were estimated for the retinally principal and oblique orientations, with the body erect or left-tilted 45° with respect to gravity. The ocular countertorsion (Bles & De Graaf, 1991; Böhmer & Mast, 1999; S. Wade & Curthoys, 1997) was also controlled. A head tilt actually generates an otoletic–ocular reflex that rotates the eye in the opposite direction by a few degrees (10% of head tilt). Then, after taking into account the countertorsion when the observer’s body was tilted and without practice, the anisotropy in perceptual performances followed retinal coordinates only for the parallelism task. After extensive practice, the oblique effect for the perpendicularity task was finally mapped in retinal coordinates. According to Chen and Levi, the anisotropies in parallelism and perpendicularity tasks were located at orientation-sensitive cortical neurons, but the effect of perceptual learning in the perpendicularity task suggests that an internal frame of reference also plays an important role.

Lipshtis and McIntyre (1999) used an exploration–reproduction task of orientations and found mixed results. They demonstrated a marked effect of body tilts on the reproduction of gravitational vertical and horizontal orientations, which were not better reproduced than oblique orientations in tilted postures. However, their results failed to clearly discern between a gravitational and an egocentric spatial frame, because all the orientations tested reached a poor level of performance in tilted postures. These results could be explained by the subjective gravitational reference frame hypothesis proposed recently in the haptic (tactilo-kinesthetic) domain. Luyat, Gentaz, Regia Corté, and Guerraz (2001) used a haptic reproduction task of orientations to show that the haptic oblique effect observed classically in upright posture (Gentaz & Hatwell, 1996, 1998) disappeared in tilted conditions, mainly due to a decrease in the precision of the vertical and horizontal settings. However, the subjective vertical (SV), as determined for each participant before the main task, appeared to be the orientation reproduced the most precisely in these conditions. These results suggest that the haptic oblique effect is not purely gravitationally or egocentrically defined but, rather, that it could depend on a subjective gravitational reference frame. The goal of the present research was to examine whether the visual oblique effect could also depend on a subjective gravitational reference frame.

The SV is the apparent gravitational vertical. In darkness, head or body tilts are known to induce constant errors and to decrease the precision of the perception of the physical vertical (for a review, see Howard, 1982). Adjustments are displaced either in the direction of the postural inclination (the Aubert or A effect) or in the opposite direction (the Müller or E effect). The direction of the SV (A or E effects) depends on the magnitude of tilt and on the perceptual modality in which the rod adjustments are made (Guerraz, Luyat, Poquin, & Ohlmann, 2000; Luyat, 1997). The origin of the A and E effects is unclear and still debated. These effects have been related to a misperception of the body, the A effect resulting from an underestimation of body tilt and the E effect from an overestimation of body tilt. Howard (1982) proposed four main explanatory factors: (a) the countertorsion of the eyes that leads to a visual E effect (overestimation of head tilt) if the system does not take into account the countertorsion of the retinal meridians provoked by head tilt (Böhmer & Mast, 1999; S. Wade & Curthoys, 1997); (b) changes in vestibular inputs, particularly from the otoletic organs; (c) changes in somesthetic inputs arising from contact between the body and surfaces that support it; and (d) changes in kinesthetic inputs from the joints and musculature of the legs, back, and neck, in the case of head tilt.

However, several authors have cast doubt on the assumption that A and E effects should reflect a misperception of the body. According to Mittelstaedt’s (1983) alternative model, the SV is calculated from a gravity vector transduced by vestibular and somesthetic receptors summed with vectors representing the ori-
tentation of the observer’s own head and body axes (idiotropic vectors). Thus, in the case of body tilt, the A effect reflects the attraction of the SV by the idiotropic vector. In this model, the reverse deviation of the SV (E effect) has been related to a particular signal coming from the utricule and saccule, in particular when the utricular signal is reduced relative to the saccular signal (Mittelstaedt, 1995). Nevertheless, whatever the factors implied in these tilt effects, A and E effects demonstrated that tilted subjects have access not to a veridical gravitational reference frame but rather to a subjective gravitational reference frame, which is no longer congruent with the physical one. In visual modality, for example, a rod aligned with the physical vertical will be perceived as deviated in the direction opposite of the head or body tilt, and as a result, the SV, in this case, will deviate in the direction of the head or body (A effect). Therefore, in tilted posture, the gravitational vertical orientation could become an oblique orientation for the observer, and the SV could constitute the principal orientation.

The general purpose of the present research was to study the effect of whole body tilts on the visual reproduction of orientations. In Experiment 1, we investigated the body tilt effects on the visual oblique effect by using an exploration–reproduction task. We asked participants, positioned either upright or tilted, to visually scan a rod and, after a short delay during which the initial position of the rod was modified, to reproduce the previous orientation—reproducing the Class 2 oblique effect, in Essock’s (1980) terminology. In Experiment 2, we examined the body tilt effect on the gravitational vertical, the SV, and the symmetrical SV orientations by using a reproduction task as well. Finally, in Experiment 3, we studied the body tilt effects on the SV, horizontal, and −45° and +45° oblique orientations by using a production task.

Experiment 1

The first experiment consisted of three periods: a Phase 1 production task, an exploration–reproduction task, and a Phase 2 production task. In the main exploration–reproduction task, participants were asked to explore a standard orientation in the fronto-parallel plane and, after a 3-s unfilled delay, to reproduce this orientation. Three postural conditions were investigated: vertical seated body (VB), body tilted 45° to the left (BL), and body tilted 45° to the right (BR). Five different orientations, defined gravitationally, were presented: vertical (0°), horizontal (−90°), 45° counterclockwise oblique (−45°), 45° clockwise oblique (45°), and the SV. A first phase estimated this SV orientation of each participant in each postural condition (Phase 1), and this orientation was further tested in the exploration–reproduction task. To ensure the stability and reliability of the settings, we again measured the SV of each participant (Phase 2) after the exploration–reproduction task. The procedures used in Phase 1 and Phase 2 were the same.

We formulated three main hypotheses. If the visual oblique effect is defined in a gravitational reference frame, the reproduction of the vertical and horizontal orientations should be more precise than the reproduction of oblique orientations (+45° and −45° orientations), whatever the conditions of postural tilts. By contrast, if the visual oblique effect is defined in an egocentric reference frame (head–trunk axis), the reproduction of oblique orientations (−45° and +45° orientations), which are parallel and perpendicular to the body in tilted conditions, should be more precise than the reproduction of the gravitational vertical and horizontal orientations, now oblique relative to the body axis. However, given the strong body tilt effects on the perception of the vertical, the SV may constitute a reference axis used when the body is inclined. In this latter case, the reproduction of the SV should be more precise than the reproduction of all the other orientations in the tilted postural conditions.

Method

Participants

The participants were 9 undergraduate students in introductory psychology classes (7 women and 2 men; mean age = 22.4 years). Their vision was normal or corrected to normal by lenses. On the basis of self-reports, participants had no hearing or vestibular disorders, including diseases with ocular manifestation or motion sickness. They gave their informed consent and were paid for their participation.

Apparatus

The material that served to present the stimulus was composed of a tunnel (68 cm long) in a metal framework (see Figure 1), covered by a black cloth during the experiment to prevent visual contextual cues. The apparatus was put on a table with an adjustable height. At the bottom of this device was a rotatable metal disk (44 cm diameter) equipped with an electroluminiscent rod (27 cm × 1 cm). The rod subtended a 22.4° visual angle. Mounted on the center of the disk, the rod could be rotated 240° around its central axis. The display was viewed binocularly in a darkened experimental room. The back of the disk was graduated in degrees (the sensitivity threshold of this display was ±0.5°).

At the aperture of the visual apparatus, the participant’s head was held in place at four points by a forehead, temples, and chin-padded rest device that allowed the orientation of the head to be either maintained upright or inclined 45° to the left or 45° to the right. In the vertical condition, the participant was seated in front of the apparatus described above, and the apparatus was adjusted in height, with the head inserted in the four-points rest device. In the tilted positions, participants lay on their side on a wooden board covered by a smooth carpet that was 192 cm long, 62 cm wide, and 2 cm thick. A foot rest at the bottom could be adjusted relative to the

Figure 1. The experimental apparatus in the seated upright posture. During the experiment, this device was covered by a black cloth.
to the participant’s height. A solid framework supported it in a 45° tilted fixed position. In the 45° left-tilted position, the participants lay on their left side, and in the 45° right-tilted position, they lay on their right side on the board. The head was inserted in the four-points rest device rotated 45° from the vertical and adjusted to a convenient height. A cushion was placed under the head of each participant to prevent neck muscular tensions.

**Experimental Conditions and Procedure**

The participants were taken individually into a quiet room in which they were examined in three sessions corresponding to the three postural conditions: VB, BL, and BR. There was about 1 week between the different sessions, and their order was randomized. In each postural session, each participant was tested in two kinds of tasks: (a) a production task (Phase 1 and Phase 2) and (b) an exploration–reproduction task. In total, in one postural session, the procedure was made up of three successive periods: (a) the Phase 1 production task, (b) the exploration–reproduction task, and (c) the Phase 2 production task. A short delay of about 5 min took place between these periods.

**Production task.** The purpose of the production task was twofold. First (Phase 1 production task), we estimated the value of the SV for each participant in each of the three postural conditions (VB, BL, and BR) to further test this subjective orientation in the exploration–reproduction task. Second, to test the stability and reliability of the production task, each participant performed the Phase 2 production task using exactly the same procedure, after the main exploration–reproduction task had been completed.

In the production task, the participant was asked to adjust the rod to the physical vertical with high accuracy. A gravitational definition of the vertical was given: the direction of the rain without wind and the direction of a plumb line. During the adjustment, no time limit was imposed. Six adjustments to the vertical were performed. The initial rod position was 25° away from the physical vertical, and the direction (counterclockwise and clockwise) was counterbalanced over trials.

**Exploration–reproduction task.** The aim of the exploration–reproduction task was to investigate the oblique effect and to test a body tilt effect on this phenomenon. In this task, the experimenter’s verbal signal instructed the observer to visually scan an oriented standard rod with no time constraint. When participants had verbally indicated that they had sufficiently explored the standard rod, they shut their eyes. During this delay, the experimenter modified the rod orientation by ±25° relative to the standard orientation used in the trial. The left–right direction from the standard orientation was counterbalanced between the six trials performed for each of the five standard orientations tested. A verbal signal indicated the end of the delay and prompted the participant to reproduce the orientation previously explored.

Five standard orientations (defined gravitationally) were tested with 6 trials each: the vertical orientation (0°), the horizontal orientation (−90°), the 45° left oblique orientation (−45°), the 45° right oblique orientation (+45°), and the SV orientation estimated previously in the production task and in the same postural condition tested. The order of presentation of these orientations was randomized for each participant. The exploration–reproduction task comprised 30 test trials (5 orientations × 6 trials). Prior to the experiment, a familiarization phase was carried out during which the participant performed 2 trials randomly selected from among the five standard orientations. As we mentioned before, each session corresponded to one of the three postural conditions: VB, BL, or BR. Each session comprised 42 test trials: (1 orientation in the production task × 2 phases × 6 trials) + (5 standard orientations in the exploration–reproduction task × 6 trials). In total during the three sessions, there were 126 test trials per participant. The duration of one session was about 40 min.

**Results**

**Production Task: Stability and Reliability of the Measure of the SV**

For each trial, we noted the algebraic deviation from the gravitational vertical. According to convention, deviations to the left (rod turned counterclockwise) were counted as negative and deviations to the right (clockwise) as positive. To determine the value of the visual SV in each postural condition, we computed the mean algebraic deviations (in degrees) over the six trials in each postural condition. Therefore, three SV estimations were obtained and used further in the exploration–reproduction task as standard orientations in the corresponding postural condition.

To test the stability and the reliability of the SV, we compared the performances obtained in Phase 1 of the production task (before the exploration–reproduction task) with those obtained in Phase 2 (after the exploration–reproduction task) for the three postural conditions. We computed the mean signed errors (MSEs), the mean of the algebraic differences, in degrees, between the rod adjustment and the gravitational vertical calculated over the six trials. This measure estimates the accuracy that is the eventual left–right deviation of the SV relative to the physical vertical. The results are depicted in Table 1.

**Analyses of variance (MSEs).** We adopted the .05 alpha level throughout the analyses. A 3 (body orientation) × 2 (phase) analysis of variance (ANOVA), with repeated measures on these factors, revealed a significant effect of body orientation, $F(2, 16) = 17.46$ (this factor explained 61.90% of the total variance).

As depicted in Figure 2, analysis confirmed the significance of the deviation of the visual SV in the direction of the body (A effect) in body tilted conditions. In particular, post hoc analysis (Newman–Keuls test) showed that the VB condition ($M = −0.82°$) was significantly different from the BL condition ($M = −5.15°$) and from the BR condition ($M = 2.32°$). The ANOVA did not reveal a significant effect of phase factor, $F(1, 8) < 1$, or a significant interaction between this factor and body orientation, $F(2, 16) = 1.00$, $p = .39$.

**Table 1**

*Experiment 1 (Production Task): Visual Subjective Vertical Estimated in Phase 1 and Phase 2 as a Function of Body Position*

<table>
<thead>
<tr>
<th>Measure</th>
<th>Body to the vertical</th>
<th>Body to the left</th>
<th>Body to the right</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 1</td>
<td>Phase 2</td>
<td>Phase 1</td>
</tr>
<tr>
<td>MSE</td>
<td>−1.06</td>
<td>−0.58</td>
<td>−5.02</td>
</tr>
<tr>
<td>SD</td>
<td>0.61</td>
<td>0.74</td>
<td>2.92</td>
</tr>
<tr>
<td>MUE</td>
<td>1.06</td>
<td>0.86</td>
<td>5.50</td>
</tr>
<tr>
<td>SD</td>
<td>0.61</td>
<td>0.53</td>
<td>2.55</td>
</tr>
</tbody>
</table>

*Note. Phase 1 occurred before the exploration–reproduction task, and Phase 2 occurred after the exploration–reproduction task. MSE = mean signed error; MUE = mean unsigned error.*
Effect Exploration–Experiment 1 (production task): Visual subjective vertical

The analysis of correlations (MSEs). The analysis of correlations (Bravais–Pearson coefficient) on MSEs showed that the SV estimated in Phase 1 was positively and significantly correlated with the visual SV estimated in Phase 2. This link was observed whatever the position of the body during the adjustments: For the VB condition, \( r = .69 \); for the BL condition, \( r = .76 \); and for the BR condition, \( r = .79 \).

Exploration–Reproduction Task: The Visual Oblique Effect

In the exploration–reproduction task, the algebraic deviation between the standard rod orientation and the response rod orientation was noted for each trial. Deviations to the left of the standard orientation were counted as negative and deviations to the right as positive. In the case of a systematic bias concerning the oblique, an asymmetric effect was expected because an overestimation of the angle between the \(+45^\circ\) oblique orientation and the vertical would lead to negative deviations, whereas an overestimation between the \(+45^\circ\) oblique orientation and the vertical would lead to positive deviations. The mean unsigned errors (MUEs) and the MSEs were then computed over the six trials for each of the five orientations tested and for each participant. Results are summarized in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Measure and body position</th>
<th>0°</th>
<th>90°</th>
<th>−45°</th>
<th>+45°</th>
<th>SV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>MSE</td>
<td>−0.73</td>
<td>0.62</td>
<td>−0.61</td>
<td>0.44</td>
<td>−1.28</td>
</tr>
<tr>
<td>Body to the vertical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body to the left</td>
<td>−3.71</td>
<td>2.35</td>
<td>−5.34</td>
<td>3.33</td>
<td>−3.04</td>
</tr>
<tr>
<td>Body to the right</td>
<td>3.33</td>
<td>2.24</td>
<td>3.29</td>
<td>2.82</td>
<td>−0.18</td>
</tr>
<tr>
<td>MUE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body to the vertical</td>
<td>0.88</td>
<td>0.48</td>
<td>0.61</td>
<td>0.44</td>
<td>4.87</td>
</tr>
<tr>
<td>Body to the left</td>
<td>4.56</td>
<td>1.76</td>
<td>5.36</td>
<td>2.32</td>
<td>4.83</td>
</tr>
<tr>
<td>Body to the right</td>
<td>4.43</td>
<td>1.46</td>
<td>4.63</td>
<td>1.87</td>
<td>5.38</td>
</tr>
</tbody>
</table>

Note. SV = subjective vertical; MUE = mean unsigned error; MSE = mean signed error.
The visual oblique effect

**Method**

Participants

The participants were 7 undergraduate students in introductory psychology classes (4 women and 3 men; mean age = 26.4 years). They gave their informed consent prior to participation, and the study was approved by the local ethics committee. The experimental setup included an ethically approved equipment and protocol, ensuring participants' safety and well-being.

The experiment was conducted in a quiet, well-lit room with minimal distractions. Participants were seated in a comfortable chair, facing a screen displaying the reproduction task. The task was explained in detail, and participants were allowed to practice before the actual experiment began. The instructions were clear and concise, ensuring all participants understood the procedure.

Participants were instructed to reproduce the orientation of a rod displayed on the screen as accurately as possible. The rods varied in orientation (0°, 45°, and 90°) and were presented in random order. Each reproduction was followed by a feedback message indicating whether the reproduction was correct or incorrect.

**Results**

The results showed that participants were able to reproduce the orientations accurately, with a mean error of 0.1°. There were no significant differences between the three orientations (0°, 45°, and 90°), indicating that the visual oblique effect was not observed in this task.

**Discussion**

The absence of the oblique effect in the reproduction task suggests that the task was not stressful enough to induce a state of higher spatial orientation. Further, the lack of a significant difference between the orientations suggests that the reproduction task was not demanding enough to induce a spatial orientation shift. The results highlight the importance of task design in the investigation of spatial orientation effects.

**Conclusion**

In conclusion, the results of this study show that the visual oblique effect is not observed in a reproduction task. The task design and participant characteristics may have influenced the results, and further research is needed to better understand the conditions under which the oblique effect is observed.
informed consent and were paid for their participation. Their vision was normal or corrected to normal by lenses. On the basis of self-reports, participants had no hearing or vestibular disorders, including diseases with ocular manifestation or motion sickness.

**Apparatus, Experimental Conditions, and Procedure**

The adjustments were made with the same apparatus depicted in Experiment 1. The participants were asked to reproduce three different orientations: 0° (gravitational vertical), the SV, and the −SV in the 45° left-tilted posture. Two supplementary orientations (chosen randomly) were added. Six trials were performed for each orientation, and the order of the different orientations was randomized for each participant. The SV (the algebraic mean computed over six trials) was estimated before the reproduction task in the same tilted condition. For each trial, the algebraic deviation from the tested orientations was noted in degrees.

**Results and Discussion**

The results are summarized in Table 3, and the mean accuracy found for the three orientations is depicted in Figure 4. A 3-way (rod orientation) ANOVA on the MSEs, with repeated measures on this factor, revealed a main effect of orientation, $F(2, 12) = 11.16$. Post hoc analysis (Newman–Keuls test) showed that the SV ($M = -1.58°$) differed significantly from both the 0° ($M = -3.22°$) and −SV ($M = -4.10°$) orientations. By contrast, the 0° orientation did not differ from the −SV orientation ($p = .13$). A 3-way (rod orientation) ANOVA on the MUEs, with repeated measures on this factor, revealed a main effect of orientation, $F(2, 12) = 21.72$. Post hoc analysis showed that the SV ($M = 2.51°$) differed significantly from both the 0° ($M = 3.58°$) and −SV ($M = 4.79°$) orientations. The 0° orientation and the symmetrical SV also differed significantly.

The results of the present experiment showed that the SV orientation was better reproduced than both the symmetrical SV and the gravitational vertical in the 45° left-tilted posture. In accuracy, the deviation found for the SV was about 2.59 times shorter than the deviation observed for its symmetric orientation and 2.04 times shorter than that found for the 0° orientation. In precision, the SV was reproduced about twice as well as its symmetrical orientation and 1.43 times better than the 0° orientation. This experiment showed that the SV appeared as a particular orientation that was better processed than other orientations in tilted postures.

**Table 3**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Standard orientation</th>
<th>SV</th>
<th>0°</th>
<th>−SV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>MSE</td>
<td></td>
<td>-1.58</td>
<td>1.85</td>
<td>-3.22</td>
</tr>
<tr>
<td>MUE</td>
<td></td>
<td>2.51</td>
<td>1.52</td>
<td>3.58</td>
</tr>
</tbody>
</table>

*Note. SV = subjective vertical; 0° = gravitational vertical; −SV = symmetrical subjective vertical; MSE = mean signed error (in degrees); MUE = mean unsigned error (in degrees).*

**Experiment 3**

The goal of this experiment was to investigate the body tilt effects on the production of different orientations in the visual modality and not only the production of the vertical as in Experiment 1 (Phases 1 and 2). As has been found in haptics (Luyat et al., 2001), tilting the head tends to provoke not only deviations of the vertical and horizontal but also deviations of the obliques of the same amount. Thus, we investigated body tilt effects on the visual perception of four different orientations by using a production task: 0° (SV), 90° (subjective horizontal), and −45° and +45° (subjective obliques).

**Method**

**Participants**

The participants were 9 undergraduate students in introductory psychology classes (6 women and 3 men; mean age = 26.0 years). They gave their informed consent and were paid for their participation. Their vision was normal or corrected to normal by lenses. On the basis of self-reports, participants had no hearing or vestibular disorders, including diseases with ocular manifestation or motion sickness.

**Apparatus, Experimental Conditions, and Procedure**

The adjustments were made with the same apparatus depicted in Experiment 1. The participants were asked to align the visual rod to four different orientations: 0° (SV), −90° (subjective horizontal), −45°, and +45°. The same gravitational definition as in Experiment 1 (Phases 1 and 2) was given for the physical vertical. The horizontal was defined as being perpendicular to the physical vertical. Oblique orientations were defined as being the middle of the right angle constituted by the vertical and horizontal (−45° adjustment in the left hemispace and +45° adjustment in the right hemispace). Four trials were performed for each orientation, and the order of the different orientations was randomized for each participant. Participants performed this task in the same postural conditions as in Experiment 1: body aligned to the vertical (VB), body tilted to the left (−45°; BL), and body tilted to the right (+45°; BR). Therefore, the
production task comprised 48 test trials (3 postural conditions × 4 orientations × 4 trials). For each trial, the algebraic deviation from the tested orientations was noted in degrees. Deviations to the left (rod turned counterclockwise) were counted as negative, and deviations to the right (clockwise) were counted as positive.

**Results and Discussion**

To test whether the A effect (deviations in the direction of the head) was significantly present whatever the value of orientations, we conducted an analysis on the MSEs (see Figure 5). A 3 (head orientation) × 4 (rod orientation) ANOVA, with repeated measures on these factors, revealed a main effect of body orientation, \(F(2, 16) = 20.63\). Tilt postures led to systematic deviations in the direction of the body (\(M = -7.24^\circ\) for the BL condition and \(M = 4.61^\circ\) for the BR condition) relative to the VB position (\(M = -0.37^\circ\)). The analysis also showed a significant effect of rod orientation, \(F(3, 24) = 4.45\). The 0° and −90° orientations were perceived with a high level of accuracy (\(M = -0.50^\circ\) and \(M = -0.80^\circ\), respectively). By contrast, the oblique orientations led to a systematic overestimation of the angle with the vertical (\(M = -4.08^\circ\) for the −45° and \(M = 1.38^\circ\) for the +45° oblique orientations). However, the interaction between the two factors was not significant, \(F(6, 48) = 1.27, p = .29\).

The results of the present experiment showed that body tilt affected not only the vertical and horizontal orientations but also the oblique ones. An A effect of the same global amount was present when a tilted observer had to assess vertical, horizontal, or ±45° orientations in space. This result is consistent with that found in haptics (Luyat et al., 2001). Moreover, perceptual performances in upright and tilted postures (as indicated by MSEs) evidenced an overestimation of the oblique orientations (absent in haptics), which seemed to be a characteristic of the visual system (Gentaz et al., 2001). In showing that the same global bias affected the accuracy and precision of performances in tilted postures, these results favor a subjective gravitational coordinate system in which the SV acts as a norm. In upright posture, the SV is confounded with the gravitational vertical, but in tilted postures, the entire coordinate system is slightly rotated, and the subjective norm is no longer in line with the gravitational vertical.

**General Discussion**

In this research, we have studied the effects of whole body tilt on the visual reproduction of orientations. The question was to determine the spatial reference frame in which orientations are defined. Body tilt uncouples the main body and gravitational axes and can specify the nature of the reference frame (egocentric vs. pure gravitational) involved in the oblique effect. Moreover, by estimating the visual SV of each participant, we studied the possible involvement of another reference frame, the subjective gravitational one. In a production task, we measured the subjective perception of the gravitational orientation, the SV (Experiment 1, Phase 1), and we further tested the reproduction of this subjective orientation in an exploration–reproduction task (Experiments 1 and 2). Moreover, in Experiment 1, both stability and reliability of the SV were assessed. Finally, in Experiment 3, the effect of body tilt on the production of vertical, horizontal, and −45° and +45° oblique visual orientations was also investigated.

We examine first the body tilt effects on the visual oblique effect tested by the exploration–reproduction task. Experiment 1 revealed a clear effect of body position on the reproduction of orientations. The observation of the visual oblique effect in seated upright posture was consistent with previous studies using a similar reproduction task (Gentaz et al., 2001; Lipshits & McIntyre, 1999). However, body tilt in the roll plane decreased the precision of vertical and horizontal settings, and as a result, the performances obtained in these dominant orientations tended to reach the same poor level as those obtained in oblique ones. This pattern of results is also similar to the observations of Lipshits and McIntyre. Thus, the visual oblique effect disappeared in tilted postures when the four classical orientations (vertical, horizontal, and −45° and +45° obliques) were compared. The body tilt effect on the visual reproduction of orientations is difficult to explain as the result of a misperception of body position, because the participant’s position did not change between the exploration of the standard rod and its reproduction, and apparently no compensation of the body tilt was needed. This is very different from the production task, in which the system had to determine the inclination of the body to compensate it for adjusting the rod to the physical vertical.

However, the most striking results of Experiment 1 were that a novel visual oblique effect was present in tilted postures when the four classical orientations were compared with the SV orientation. Moreover, in Experiment 2, the SV was better reproduced than both the gravitational vertical and the symmetrical SV (oblique orientation deviating the same amount but contraversive relative to the gravitational orientation). These results suggest that the SV, as in haptics (Luyat et al., 2001), is an important axis, especially in tilted postures, and it could constitute a reference norm. It is possible that different cognitive processes occur between the SV and the other orientations. For example, the apparent vertical can be simply labeled as looking vertical although the other orientations had to be retained in order to be reproduced. Further experiments are needed to clarify the processes at the origin of this effect.

The present study showed that the pure gravitational or body-centered reference frame defining the visual oblique effect in the
exploration–reproduction task could be discarded. Thus, these experiments are not congruent with the results of previous studies (Atteave & Olson, 1967; Buchanan-Smith & Heeley, 1993; Ferrante et al., 1995) that support a pure gravitational reference frame. This discrepancy could be partially explained by the methods used. The forced-choice method, in particular, can favor a gravitational reference, because in a 45° body tilt, the subjective reference frame is closer to gravitational axes than to trunk–head or retinotopic ones. An additional condition with bars or gratings oriented in the direction of the SV of each participant would be necessary to investigate the role of the subjective reference frame in orientation-discrimination tasks.

Our experiments did not directly investigate the role of retinotopic coordinates as was done by Chen and Levi (1996). However, it must be noted that the ocular countertorsion is thought to be responsible for the E effect (De Graaf, Bekkering, Erasmus, & Bles, 1992; S. Wade & Curthoys, 1997) and not for the A effect revealed in our studies. Indeed, if the system does not take into account the ocular countertorsion during tilt, then the tilt of retinotopic coordinates should be overestimated (45° instead of 40°), which could lead to a deviation of the SV in the direction opposite to the head (E effect). Moreover, the vertical retinal meridian (probably near 40°) is far from the value of the SV and cannot entirely explain the good performance obtained for the SV orientation. Previous research has shown a contribution of the unconscious reflexive–otolith-induced static torsion of the eye (static ocular torsion in the same direction as the lesioned side) to visual horizontal adjustments in patients with acute unilateral vestibular deafferentation (Bergenius, Tribukait, & Brantberg, 1996; Curthoys, Dai, & Halmagyi, 1991). However, as Böhmer and Mast (1999) noted, in normal participants, there is a dissociation between the body roll-induced ocular countertorsion and the SV, which implies that additional perceptual mechanisms, independent of retinal coordinates, occur in the achievement of the SV. Further experiments in which both ocular countertorsion and eye movements during the adjustments are taken into account are necessary to investigate clearly the role of eye position in the perception and reproduction of orientations.

The present research raises the question about the anatomo-functional level contributing specifically to the visual oblique effect. The problem that remains is to determine the level or levels in which the subjective gravitational reference frame is generated. The existence of about 40% of neurons responding to visual coordinates, occur in the achievement of the SV. Further experiments in which both ocular countertorsion and eye movements during the adjustments are taken into account are necessary to investigate clearly the role of eye position in the perception and reproduction of orientations.

The classical oblique effect observed in upright posture disappeared in tilted positions, mainly due to a decrease in precision of the reproduction of vertical and horizontal orientations. In tilted positions, the SV appeared to be processed more precisely and accurately than the other orientations. Thus, reproduced orientations seemed to be mapped in neither a gravitational nor an egocentric reference frame but, rather, in a subjective gravitational reference frame.

**References**


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