The reproduction of vertical and oblique orientations in the visual, haptic, and somato-vestibular systems

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This study investigates whether the vertical orientation may be predominantly used as an amodal reference norm by the visual, haptic, and somato-vestibular perceptual systems to define oblique orientations. We examined this question by asking the same sighted adult subjects to reproduce, in the frontal (roll) plane, the vertical (0°) and six oblique orientations in three tasks involving different perceptual systems. In the visual task, the subjects adjusted a moveable rod so that it reproduced the orientation of a visual rod seen previously in a dark room. In the haptic task, the blindfolded sighted subjects scanned an oriented rod with one hand and reproduced its orientation, with the same hand, on a moveable response rod. In the somato-vestibular task, the blindfolded sighted subjects, sitting in a rotating chair, adjusted this chair in order to reproduce the tested orientation of their own body. The results showed that similar oblique effects (unsigned angular error difference between six oblique orientations and vertical orientation) were observed across the three tasks. However, there were no positive correlations between the visual, haptic,

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and somato-vestibular oblique effects. Moreover, in some oblique orientations, there was a tendency to overestimate the angle between the oblique orientation and the vertical orientation. This effect varied according to the orientation value and the modality. Taken together, these findings suggest that although vertical orientation is used as a reference norm in the visual, haptic, and somato-vestibular systems to define oblique orientations, specific processing mechanisms seem to be at work in each perceptual system.

This study addressed the question of the human reproduction of vertical and oblique orientations in the visual, haptic (tactual-kinesthetic), and somato-vestibular systems. We live in a world organized by the force of gravity, which acts continuously on the body. When we are standing upright, the vertical and horizontal orientations are sensorily “over-reinforced” because of the convergence of the various cues provided by the visual system (which codes the numerous vertical and horizontal visual directions present in the environment), the vestibular system (which codes the gravitational acceleration), the muscular and articulatory endocaptors (which regulate the balance of muscular tonicity), and the cutaneous exocaptors (which record the relative pressure across the sole of the feet). Thus, the vertical and horizontal orientations may constitute powerful norms for the perceptual systems involved in spatial perception (for a recent review, see Marendaz, 1998).

The first aim of the present research was to investigate whether the vertical orientation is predominantly used as a reference norm by the visual, haptic, and somato-vestibular systems to define the oblique orientations. This would explain the existence of an anisotropic orientation processing (i.e., which differs according to the value of the orientation). In this case, an “oblique effect” (Appelle, 1972) and/or a “tilt normalization” (Howard, 1982) should be observed. An oblique effect reflects the more accurate processing of vertical or horizontal orientations relative to oblique orientations. A tilt normalization reflects a systematic directional bias where the estimates of oblique orientations are closer to the vertical or horizontal norms than to the standard stimuli. The second aim was to investigate whether the vertical reference norm is amodal or modal. In this context, an amodal reference norm would be a common norm to the three perceptual systems. This would be consistent with the assumption that a common processing mechanism is at work in all three modalities. By contrast, a modal reference norm would be specific to each perceptual system and would suggest that each system processes orientation information in specific ways depending on its particular neuronal organization.

In the visual system, the oblique effect has been shown with two general classes (comparison and reproduction) of psychophysical methods (for a recent review, see Gentaz & Ballaz, 2000). In comparison methods (e.g., Chen & Levi, 1996; Heeley, Buchanan-Smith, Cromwell, & Wright, 1997; Orban, Vandenbussche, & Vogels, 1984), a pair of rod-orientations (or gratings), for example, is presented sequentially or simultaneously. The first rod is the reference (standard) orientation and the second rod is the test orientation, which varies symmetrically around the reference orientation. The subject is asked to say whether the test orientation is tilted clockwise or counterclockwise from the reference orientation. Results typically reveal an oblique effect: The thresholds of oblique discriminations are higher than those of vertical or horizontal orientations. In reproduction methods (Appelle & Gravetter, 1985; Lechelt, Elik, & Tanne, 1976; Lechelt & Verenka, 1980), the subject perceives an oriented stimulus rod and is asked to give verbal indications to adjust a response rod at the same orientation. The unsigned angular differences in degrees between the position of the stimulus rod and that of
the response rod estimates the accuracy of the settings. The standard finding is an oblique effect—that is, significantly lower errors in the vertical horizontal orientations than in the 45°–135° oblique orientations. The visual tilt normalization is observed with comparison methods (Dick & Hochstein, 1989), but not with reproduction methods (Appelle & Gravetter, 1985; Lechelt, Eliuk, & Tanne, 1976; Lechelt & Verenka, 1980). In these studies, the analysis of the signed (constant) angular errors did not show systematic deviation.

The explanations of the visual oblique effect and the tilt normalization effect are still unclear. The origin of the oblique effect seems to be multi-component and to occur at different levels of orientation processing (for recent reviews, see Gentaz & Ballaz, 2000; Heeley et al., 1997; Saarinen & Levi, 1995). As far as the origin of the tilt normalization is concerned this effect has only been observed in the tasks measuring the basic functioning of the visual system. Howard (1982, p. 155) therefore suggested that the tilt normalization towards the vertical or horizontal orientations was due to a permanently higher sensitivity of orientation detectors for these main visual meridians (see also, Dick & Hochstein, 1989).

In the haptic system, the oblique effect has been explored less often, and the available studies used only the reproduction methods (for a recent review, see Gentaz, 2000). In these studies, blindfolded subjects were asked to explore haptically a rod with one hand and to reproduce its orientation with either the same or the other hand (Appelle & Countryman, 1986; Appelle & Gravetter, 1985; Gentaz & Hatwell, 1995, 1996, 1998, 1999; Lechelt et al., 1976; Lechelt & Verenka, 1980). Gentaz and Hatwell (1996) showed that the occurrence of the haptic oblique effect (i.e., higher unsigned errors in the oblique orientations than in the vertical–horizontal orientations) was influenced by the conditions of manual exploration because these conditions changed the gravity constraints during scanning. According to these authors, the gravitational cues provided by the antigravitational forces developed by the scanning arm–hand system could affect the magnitude of the oblique effect because these cues reinforced the vertical orientation relatively to the oblique orientations. Indeed, in the three planes of space (horizontal, frontal, and sagittal), the oblique effect was present when the forearm was free (unsupported) in the air. In this condition, antigravitational forces were elicited during the scanning. By contrast, the oblique effect was absent in the horizontal plane when the forearm was supported while remaining in physical contact with the surface of the device. In this condition, minimal antigravitational forces were required to move the forearm–hand system. In addition, the oblique effect was lowered in the frontal and sagittal planes when the forearm was lightened by a device consisting of a set of weights and pulleys. In these last two conditions, the antigravitational forces were reduced during the scanning. As far as the tilt normalization effect was concerned, the analysis of the signed (constant) errors in all haptic studies did not reveal that the reproduction of oblique orientations were closer to the vertical or horizontal standard stimuli (Appelle & Countryman, 1986; Appelle & Gravetter, 1985; Gentaz & Hatwell, 1995, 1999; Lechelt et al., 1976; Lechelt & Verenka, 1980). Moreover, some research showed an overestimation—that is, systematic errors in oblique orientations in the opposite direction to the tilt normalization (Gentaz & Hatwell, 1996).

In the somato–vestibular system, the oblique effect has not been studied directly. We defined the somato–vestibular system as the sensorial systems relying on graviceptive cues (in particular, vestibular, cutaneous, and visceral cues) to estimate the body position in space. However, the perception of orientations in this system has been studied by asking restrained subjects (either sitting in a rotating chair or lying on a tiltable board) to reach posturally a given
orientation (body adjustment). Previous results showed that the vertical body adjustments in the dark were very accurate (Anastasopoulos, Haslwanter, Bronstein, Fetter, & Dichgans, 1997; Bis dorff, Anastasopoulos, Bronstein, & Gresty, 1995; Bis dorff, Wosley, Anastasopoulos, Bronstein, & Gresty, 1996). The horizontal body adjustments were also reached with a good accuracy when the subjects had the full control of their posture and tilted themselves on the tiltable board (Mittelstaedt, 1995). However, the accuracy seemed to be lower when the subjects were not free to tilt the board but managed their orientation via remote control (Mast & Jarchow, 1996). Relatively few experiments have investigated body orientation relative to oblique orientations. Ito and Gresty (1997) have tested the postural orientation relative to the vertical, to the 45° forward and backward, and to the horizontal orientations (Protocol 3, normal subjects). Although the comparison of the different orientations (i.e., oblique effect) was not the main focus of the authors, the results tended to reveal an oblique effect with, in some conditions, either a more systematic bias for the oblique orientations than for the vertical or a higher within-subjects variability for the oblique orientations than for the vertical (Protocol 5, in particular). These results were consistent with Cohen and Larson’s (1974) findings. In the frontal plane, and with both verbal estimation (Experiments 1–3) and body adjustment task (Experiment 4), Higashiyama and Koga (1998) observed in sitting subjects that the small tilts of less than 45° were estimated correctly, whereas the large tilts of 45°–108° were overestimated. However, the analysis of within- and between-subjects variability of estimations suggested an oblique effect for the smallest tilts: Variability was the least for the gravitational vertical, increased up to the body tilt of 60°, decreased for the tilts of 60°–90°, and again increased for the tilts of more than 90°. By contrast, Nemire and Cohen (1993), who investigated body adjustments in the sagittal plane (head, trunk, and legs in alignment), failed to observe a postural oblique effect in dark condition.

Given the numerous experimental paradigms used in previous experiments to study the anisotropic orientation processing, Essock et al. (Essock, 1980; Essock, Krebs, & Prather, 1997) have proposed a distinction between the oblique effects depending on whether the task emphasizes sensory abilities (Class 1) or cognitive abilities (Class 2). The Class 1 oblique effects are those observed in the tasks that measure the basic functioning of the perceptual system: acuity, contrast threshold, and other measures of sensitivity. The Class 2 oblique effects are those observed in tasks such as identifying, remembering, or categorizing the orientations of stimuli. Essock et al. (1997) proposed that the Class 2 oblique effects could be explained by a general perceptual bias in the representation of stimulus orientation. We hypothesized that this bias could stem from the fact that any oblique orientation could be encoded in relation to the vertical and horizontal amodal norms defined by gravity constraints, whereas the vertical or horizontal orientations would be encoded directly. The indirect encoding of the oblique orientations, which implies the integration of the parameters computed on the two norms, may require higher costs of processing than the direct encoding of vertical or horizontal orientations, which refers to one norm only. The difference between these two modes of encoding and processing could explain the Class 2 oblique effects (Foster & Westland, 1998; Gentaz, 2000; Gentaz & Hatwell, 1996, 1998, 1999; Regan & Price, 1986).

In the present research, we examined the reproduction of vertical (0°), ±45°, ±30°, and ±15° oblique orientations in the visual, haptic, and somato-vestibular systems. We proposed a reproduction task in order to examine Class 2 oblique effects—that is, those depending on cognitive abilities. We investigated whether similar oblique effects (unsigned error difference
between oblique orientations and vertical orientation) and an eventual systematic directional bias (signed error in oblique settings) would be present in the three modalities when similar experimental paradigms were used and when the same subjects performed the three tasks. If this was actually observed, it would suggest that a vertical reference norm, based on gravity cues, is at work in these three perceptual systems. In addition, our aim was to analyse the correlations between the magnitude of the visual, haptic, and somato-vestibular effects of the subjects. Previous studies on the oblique effect in the different modalities were performed on independent groups of participants and therefore could not provide data on the intra-individual consistency of the effect across modalities. In the present research, we questioned whether the magnitude of the oblique effect was correlated in the three tasks. If such a correlation was observed, it would suggest that a common factor (an amodal reference norm or a general perceptual bias) underlies the processing of orientation information in the visual, haptic, and somato-vestibular systems.

**Method**

**Subjects**

The subjects were 36 volunteer male adults recruited at Centre de Recherches du Service de Santé des Armées (CRSSA) of La Tronche-Grenoble. In conformity with the Helsinki Convention, which controls and regulates human experimentation, informed consent was obtained from all subjects.

**Apparatus**

In the visual apparatus, the stimulus was a picture slide projected onto a black screen. The device consisted of a projector (3250 ALC SIMDA DATAVISION), which was used to project the line-rod. The rod projection was 50 cm long and 1.5 cm wide. The subject viewed the rod with his head upright and was sitting 100 cm away from the screen. Thus, the rod subtended a visual angle of approximately 28°. The rod was the only object visible in an otherwise entirely dark room. The subject’s body was covered with a black cloth in order to avoid the perception of the rod luminosity reflection. The line-rod was rotated in the frontal plane and was centred on the subject’s body midline. The experiment was computer driven. The subject could modify the orientation of the line-rod by means of a joystick, which controlled the orientation of the projector. The sensitivity threshold of this display was lower than 0.5°.

The haptic apparatus was composed of a black metal disc (diameter 40 cm) equipped with a rod (25 × 1.8 cm). The rod was mounted above the centre of the disc and could be rotated by 360° around its central axis. Magnets were used to maintain the rod in the desired orientation and to prevent involuntary deviation from its position during haptic scanning. The rod was connected with a potentiometer, which indicated (in degrees) the extent to which its orientation deviated from gravitational vertical. The rod was 8 cm away and parallel to the disc. The disc and rod were positioned in the frontal plane and were centred on the subject’s body midline. The blindfolded subjects sat in the front midline of the apparatus and were asked to maintain their trunk upright. The height of the disc-rod was adjusted with reference to the subject’s height: The top of the disc was at the level of the subject’s shoulders. The sensitivity threshold of this display was lower than 0.5°.

The somato-vestibular apparatus was composed of a metal board positioned in the frontal plane and equipped with a padded chair. The blindfolded subject was seated and restrained in the chair with the head aligned with the body by means of a neck brace. The chair could be tilted in the roll axis between −70° and + 70° (with a velocity varying between 3°/s and 5°/s). This constraint was important to note because it determined the value of the orientations tested in the three tasks. The chair was computer
driven. The subject could modify its orientation in the roll axis by means of a joystick, which controlled the orientation of the chair. The sensitivity threshold of this display was lower than 0.5°. The axis of the body rotation was located at the level of the middle of the ears in order to minimize the additional accelerative vestibular cues.

**Experimental conditions and procedure**

Each subject was tested individually. The subject was asked to explore the stimulus rod and, after a 10 s unfilled delay, to reproduce the same orientation. No time constraint was imposed in the presentation phase of the stimulus or the reproduction (response) phase. The 10-s delay was used to modify the orientation of the stimulus between the presentation and reproduction phases because the same stimulus was used as a standard and a response alternately. In particular, in visual and haptic tasks, the rod was moved from its initial standard position, and in the somato-vestibular task, the position of body itself was changed by the experimenter. It is noteworthy that, in the somato-vestibular task and by contrast to the other tasks, the delay was not properly “unfilled” because the subject was passively moved. In the three tasks, the initial orientation of the response rod (luminous or metal rods) or the body was ±20° relative to the standard orientation tested during the trial. Each subject was tested in the visual, haptic, and somato-vestibular tasks. The order of presentation of the three tasks was counterbalanced across subjects. The duration of each task was about 35 min. A 10-min delay was proposed between the tasks. The duration of the whole session was about 2 h 15 min for each of 36 subjects.

In the visual task, an auditory starting signal informed the subject that the luminous standard rod would appear and should be examined with no time constraint. The subject pushed a button on the joystick when his visual exploration of the stimulus was ended. Then, the subject saw a mask composed of randomized luminous dots during the 10-s delay projected by the slide projector in order to avoid the potential problems raised by iconic memory. During this 10-s delay, the experimenter modified the stimulus orientation by ±20° relative to the standard orientation used during the trial. An auditory signal indicated the end of the 10-s delay and allowed the subject to reproduce the orientation previously observed with the joystick (with no time constraint). The subject pushed the button of the joystick when the adjustment was ended. The subject saw a mask before the projection of next stimulus.

In the haptic task, a starting verbal signal of the experimenter asked the blindfolded subject to scan haptically, with the dominant hand, the oriented standard rod over its full length, and with no time constraint. The subjects used their preferred hand for writing (34 out of 36 subjects used their right hand). The subject moved his hand off the rod when the haptic exploration of the stimulus was ended. During the 10-s delay, the subject was asked to maintain the hand in contact with his abdomen, and the experimenter modified the stimulus orientation by ±20° relative to the standard orientation used during the trial. A verbal signal indicated the end of 10-s delay and asked the subject to reproduce the orientation previously explored with the same hand (with no time constraint).

In the somato-vestibular task, a starting auditory signal allowed the blindfolded subject to encode a body orientation given by the experimenter via the tiltable chair, with no time constraint. The subject pushed the button of the joystick when encoding was ended. Then, during the 10-s delay, the experimenter modified the subject’s body orientation by ±20° relative to the standard postural orientation used during the trial. An auditory signal indicated the end of this delay and allowed the subject to reproduce (by moving the joystick) the standard orientation of the body previously proposed (with no time constraint). The subject pushed the button of the joystick when the adjustment was ended. The velocity of rotation of the chair was varied by the experimenter in order to prevent any potential link between body position and time of rotation.

Seven orientations were tested in each task: −45° (right-slanting oblique in relation to an upright observer’s view), −30°, −15°, 0° (vertical aligned with the gravitational axis in the frontal plane), +15°, +30°, +45° (left-slanting oblique in relation to an upright observer’s view). Each subject performed 2
test trials in each of the seven orientations in a randomized order and each of the three perceptual tasks in a counterbalanced order (i.e., 42 test trials per subject). In addition, a familiarization phase was conducted before each perceptual task. In it, the subject performed 3 trials randomly selected among the seven test orientations. In total, there were 51 trials per subject. No feedback was given to the subject during the experiment.

**Results**

Data analyses were carried out on the angular difference (in degrees) between the positions of the standard and the response stimuli. The mean error (unsigned and signed) was then calculated for each of the seven orientations for each of the 36 subjects. The mean (unsigned and signed) errors for each condition are shown in Table 1.

**Mean unsigned errors (MUE)**

*Analyses of variance (ANOVAs).* In order to know whether an oblique effect (high error difference between six oblique orientations and vertical orientation) was present, we analysed the mean unsigned errors. As stated previously, mean unsigned errors are generally considered as a good estimate of the accuracy of response settings. Because absolute errors have generally an asymmetrical distribution, a logarithmic transformation, \( \log(x + 1) \), was carried out on each angular difference in order to fulfil the normality condition required for the ANOVA (Abdi, 1987). The Lilliefors test (Lilliefors, 1967) for normality showed that the difference between the normal and the empirical distribution of scores in degrees before transformation was significant, \( L(\text{calculated}) > L(\text{critical}), p < .01 \), whereas the difference between the normal and the empirical scores after their log transformation was not. Table 1 indicates the mean unsigned errors before transformation (deg) and after their log transformation (log). In the following analysis of results, the mean values are presented both before and after transformation.

A 3 (perceptual task) \( \times 7 \) (orientation) ANOVA (with repeated measures on the two factors) on unsigned errors in log revealed a main effect of orientation, \( F(6, 210) = 24, p < .01 \). The measurement of the oblique effect was carried out by a pre-planned contrast between the six oblique orientations and the vertical (0°) orientation. This oblique effect was significant, \( F(1, 210) = 140, p < .01 \): Errors were greater in the six oblique orientations (\( M \) in deg = 4.9°; \( M \) in log = 1.04°) than in the vertical orientation (\( M \) in deg = 2.5°; \( M \) in log = 0.47°). The Orientation \( \times \) Perceptual Task interaction was significant, \( F(12, 420) = 4.1, p < .01 \). The analysis of this interaction showed that the effect of orientation was significant in the visual, \( F(6, 210) = 26, p < .01 \); haptic, \( F(6, 210) = 2.44, p < .01 \), and somato-vestibular, \( F(6, 210) = 8.6, p < .01 \), tasks. In the visual task, the oblique effect was significant: obliques, \( M \) in deg = 3.6°; \( M \) in log = 0.62°; vertical, \( M \) in deg = 0.9°; \( M \) in log = 0.28°; \( F(1, 35) = 2.44, p < .01 \); Figure 1. Moreover, post hoc analyses (Newman–Keuls test, with a .01 alpha level) on the visual responses showed no difference between the \(-45°\) and \(+45°\) orientations, the \(-30°\) and \(+30°\) orientations, or the \(-15°\) and \(+15°\) orientations. However, the \( \pm 45° \) and \( \pm 15° \) settings (which did not differ) were lower than the \( \pm 30° \) settings and were greater than in the 0° settings. In the haptic task, the oblique effect was significant: obliques, \( M \) in deg = 5.7°; \( M \) in log = 0.77°; vertical, \( M \) in deg = 4°; \( M \) in log = .63°; \( F(1, 35) = 9.2, p < .01 \); Figure 2. Moreover, post hoc analyses on haptic oblique responses showed that the \( \pm 45°, \pm 30°, \) and \( \pm 15° \) settings were not different. Finally, in the somato-vestibular task, the oblique effect was significant: obliques, \( M \) in deg =
4.3°; $M$ in log = .69°; vertical, $M$ in deg = 2.6°; $M$ in log = 0.52°; $F(1, 35) = 2.44, p < .01$; Figure 3. Moreover, post hoc analyses on somato-vestibular oblique responses showed no significant different between the ±45°, ±30°, and ±15° settings.

Analyses of correlations. In order to investigate whether links existed between the oblique effects observed in the visual, haptic, and somato-vestibular tasks in the same subjects, an analysis of correlation between the magnitudes (in log) of these three oblique effects (i.e., the magnitudes of the unsigned error difference between the vertical orientation and the six oblique orientations) for each subject was performed. The Bravais–Pearson test between the visual, haptic, and somato-vestibular oblique effects failed to reveal any significant correlation (Table 2).

**TABLE 2**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Visual $M$</th>
<th>Visual SD</th>
<th>Haptic $M$</th>
<th>Haptic SD</th>
<th>Somato-vestibular $M$</th>
<th>Somato-vestibular SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>– 45°</td>
<td>3.1</td>
<td>1.8</td>
<td>6.1</td>
<td>3.3</td>
<td>4.1</td>
<td>2.3</td>
</tr>
<tr>
<td>MUE-log</td>
<td>0.58</td>
<td>0.18</td>
<td>0.80</td>
<td>0.20</td>
<td>0.66</td>
<td>0.19</td>
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<tr>
<td>MSE-deg</td>
<td>0.7</td>
<td>2.5</td>
<td>1.7</td>
<td>5.0</td>
<td>–0.5</td>
<td>3.9</td>
</tr>
<tr>
<td>– 30°</td>
<td>4.4</td>
<td>2.2</td>
<td>5.4</td>
<td>3.3</td>
<td>4.9</td>
<td>2.6</td>
</tr>
<tr>
<td>MUE-log</td>
<td>0.70</td>
<td>0.18</td>
<td>0.75</td>
<td>0.24</td>
<td>0.73</td>
<td>0.19</td>
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<tr>
<td>MSE-deg</td>
<td>1.3</td>
<td>3.4</td>
<td>1.9</td>
<td>3.9</td>
<td>0.2</td>
<td>2.7</td>
</tr>
<tr>
<td>– 15°</td>
<td>3.3</td>
<td>1.7</td>
<td>5.3</td>
<td>2.7</td>
<td>4.7</td>
<td>2.1</td>
</tr>
<tr>
<td>MUE-log</td>
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<td>0.17</td>
<td>0.76</td>
<td>0.17</td>
<td>0.73</td>
<td>0.15</td>
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<td>–0.02</td>
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<td>0.8</td>
<td>2.3</td>
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<tr>
<td>0°</td>
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<td>0.6</td>
<td>3.8</td>
<td>2.6</td>
<td>2.6</td>
<td>1.7</td>
</tr>
<tr>
<td>MUE-log</td>
<td>0.28</td>
<td>0.14</td>
<td>0.61</td>
<td>0.25</td>
<td>0.52</td>
<td>0.17</td>
</tr>
<tr>
<td>MSE-deg</td>
<td>0.4</td>
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<td>–0.5</td>
<td>2.7</td>
<td>0.5</td>
<td>1.8</td>
</tr>
<tr>
<td>+ 15°</td>
<td>3.2</td>
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<td>3.1</td>
<td>1.3</td>
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<tr>
<td>MUE-log</td>
<td>0.60</td>
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<td>0.77</td>
<td>0.19</td>
<td>0.59</td>
<td>0.15</td>
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<tr>
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<td>2.6</td>
<td>4.9</td>
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<tr>
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<td>1.3</td>
<td>4.7</td>
<td>0.7</td>
<td>3.1</td>
</tr>
<tr>
<td>+ 45°</td>
<td>2.8</td>
<td>1.2</td>
<td>5.8</td>
<td>3.4</td>
<td>4.2</td>
<td>2.1</td>
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<tr>
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<td>0.77</td>
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<td>0.9</td>
<td>5.9</td>
<td>1.9</td>
<td>3.2</td>
</tr>
</tbody>
</table>

MUE-deg = unsigned angular errors in degrees.
MUE-log = unsigned angular errors after the log transformation.
MSE-deg = signed angular errors in degrees.
Mean signed errors (MSE)

It was interesting to know whether an eventual systematic directional bias (signed error in oblique settings) appeared when the same subjects perform the three tasks because previous studies could not provide consistent data on this question (see Introduction). Therefore, we attributed a negative sign to the subject’s response if the response rod was positioned between the standard and the vertical orientations, and a positive sign if the response was positioned between the standard and the vertical orientations. For the vertical (0°) orientation, a positive sign was attributed if the response was positioned clockwise to this orientation, and a negative sign was attributed if the response was positioned counterclockwise. For each task, the mean relative to each orientation was compared to the vertical (0°)–norm mean (μ = 0°). A Bonferroni alpha-level correction was adopted (α = .007).

**TABLE 2**

<table>
<thead>
<tr>
<th></th>
<th>Visual</th>
<th>Haptic</th>
<th>Somato-vestibular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haptic</td>
<td></td>
<td>0.11</td>
<td>1</td>
</tr>
<tr>
<td>Somato-vestibular</td>
<td>−0.05</td>
<td>0.28</td>
<td>1</td>
</tr>
</tbody>
</table>

* Bravais-Pearson r. The magnitude of unsigned errors in log between the vertical orientation and the six oblique orientations.

Figure 1. Mean unsigned angular errors in log (± standard errors) as a function of stimulus orientation in the visual task.
Figure 2. Mean unsigned angular errors in log (± standard errors) as a function of stimulus orientation in the haptic task.

Figure 3. Mean unsigned angular errors in log (± standard errors) as a function of stimulus orientation in the somato-vestibular task.
In the visual task, \( t \)-test comparisons (\( \alpha = .007 \)) showed that three oblique orientations were overestimated: the –15° (\( M = 1.19° \), the +15° (\( M = 1.76° \)), and the +30° orientations (\( M = 1.86° \)) were respectively different from the vertical-norm mean. There was a slight tendency for the vertical orientation to deviate in the clockwise direction (\( M = .44° \); \( p = .009 \)). All other comparisons were not significant. In the haptic task, \( t \)-test comparisons (\( \alpha = .007 \)) showed two oblique orientations, the –30° (\( M = 1.98° \)) and +15° (\( M = 2.64° \)), were significantly overestimated. All other comparisons were not significant. In the somato-vestibular task, \( t \)-test comparisons failed to show a significant systematic bias, except for the +45° orientation, which was overestimated (\( M = 1.88° \)).

**GENERAL DISCUSSION**

In this research, we studied the reproduction of orientations in the visual, haptic, and somato-vestibular systems. We examined whether the vertical orientation was predominantly used as an amodal reference norm by the three perceptual systems to define oblique orientations. We investigated this question by asking the same subjects to reproduce, in the roll (frontal) plane, the vertical (0°), ±15°, ±30°, and ±45° orientations in visual, haptic, and somato-vestibular tasks.

We shall first examine the orientation effect in each perceptual system. In the visual system, the oblique effect was demonstrated by means of the classical exploration–delay–reproduction task used mainly in the haptic literature. The result was similar to those obtained in the visual domain with the reproduction methods and confirmed that this effect is present whatever the experimental methods (see Introduction). Moreover, our results revealed, in the reproduction of oblique orientations, a tendency to overestimate the angle between the oblique and the vertical orientations. However, the statistical analysis showed that only three oblique orientations were significantly overestimated. These results are not in line with the hypothesis of a tilt normalization phenomenon. They are consistent with the suggestion that the tilt normalization phenomenon, which has been observed only in tasks measuring the basic functioning of the visual system, may be due to a permanently higher sensitivity of orientation detectors for the main (vertical and horizontal) visual meridians (Dick & Hochstein, 1989; Howard, 1982). However, the absence of a systematic bias for all oblique orientations is difficult to explain, and further research (with more trials per condition) should clarify this question.

In the haptic system, the oblique effect measured by the mean unsigned errors was significant. This result is consistent with the previous results reported by Gentaz and Hatwell (1996) showing that when a reproduction task is performed in the frontal plane (with a 5-s unfilled delay), the oblique effect is present, probably because of the gravitational cues provided by the arm–hand system during scanning. The analysis of mean signed errors did not show a systematic bias but only a tendency to overestimate two oblique orientations (the +15° and the –30° orientations) The presence of such positive errors was consistent with some previous results reported by Gentaz and Hatwell (1996).

In the somato-vestibular system, an oblique effect was found in a task involving a postural adjustment in the roll plane to previously encoded orientations. In this system, the vertical body orientation was reproduced better than oblique body orientations. This result is in line
with those obtained by Cohen and Larson (1974), Ito and Gresty (1997), and Higashiyama and Koga (1998; concerning the within-subjects variability) using different tasks. The main difference of the task used here was that the subject had to encode (without time constraint) an orientation before having to reproduce it. Therefore, response was mainly based on sensory encoding of orientation stored in short-term memory, whereas in Higashiyama and Koga’s study the subject’s response was mainly based on the representation of spatial orientations stored in long-term memory. It is noteworthy that in our research, no directional error was observed in oblique orientation reproductions, except for the +45° orientation in which an overestimation of body tilt was present. These results are consistent with the results reported by Higashiyama and Koga, who found that small tilts of less than 45° were estimated with no directional error whereas the large tilts over 45° were overestimated.

The comparison of performance (MUE) within oblique orientations revealed no significant difference between each pair of orientations in the three perceptual systems. This symmetry is consistent with the assumption that the vertical orientation was used by the three perceptual systems as a reference norm to define oblique orientations. Moreover, results showed that errors increased as the angle relative to the vertical increased, but that this increase was non-linear. The improvement of the performances in the ±45° oblique orientations relative to the ±30° oblique orientations was significant in the visual system only. These findings are consistent with the assumption that the ±45° oblique may be used in vision as another dominant norm (Forster & Westland, 1998; Regan & Price, 1986; Yakimoff, Lansky, Mitrany, & Radil, 1989).

The final theoretical point concerns the correlation analysis. The occurrence of similar oblique effects in the different perceptual channels may suggest that an amodal reference norm could be at work across perceptual systems. However, the correlation analysis failed to show any statistical link between the magnitude of the visual, haptic, and somato-vestibular oblique effects (non-reject of null hypothesis). Therefore, this research did not provide a support in favour of a common processing mechanisms accounting for the whole variance of the oblique effects. If the observed lack of correlation is confirmed in further research, it would mean that, although the vertical orientation appears to be used as a reference norm, modality-specific mechanisms are involved in the processing of this vertical modal norm. As a result, these mechanisms affect the magnitude of errors in ways that vary from one modality to the other and preclude the manifestation of correlations of the observed oblique effects.

In conclusion, the most striking results of the present study were that, in an orientation reproduction task, similar oblique effects were present in the visual, haptic, and somato-vestibular systems of the same subjects. No positive correlation between these visual, haptic, and somato-vestibular oblique effects was observed. These findings suggest that the vertical orientation is used as a modal reference norm by the visual, haptic, and somato-vestibular systems to define oblique orientations. Further research should study whether the horizontal orientation is also used as a modal reference norm by the different systems. However, specific processing mechanisms seem to be at work in each modality. The nature of these mechanisms, which depend probably on the neuronal and psychophysical functioning of each modality (Gentaz & Rossetti, 1999; Hatwell, Streri, & Gentaz, 2000; Millar, 1994), should be examined further.
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