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Effects of external feedback about body tilt: Influence on the Subjective Proprioceptive Horizon

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Abstract

The present study investigated a cognitive aspect upon spatial perception, namely the impact of a true or false verbal feedback (FB) about the magnitude of body tilt on Subjective Proprioceptive Horizon (SPH) estimates. Subjects were asked to set their extended arm normal to gravity for different pitch body tilts up to 9°. True FB were provided at all body tilt angles, whereas false FB were provided only at 6° backward and 6° forward body tilts for half of the trials. Our data confirmed previous results about the egocentric influence of body tilt itself upon SPH: estimates were linearly lowered with forward tilts and elevated with backward tilts. In addition, results showed a significant effect of the nature of the external FB provided to the subjects. When subjects received a false FB inducing a 3° forward bias relative to physical body tilt, they set their SPH consequently higher than when they received a false FB inducing a 3° backward bias. These findings clearly indicated that false cognitive information about body tilt might significantly modify the judgement of a geocentric direction of space, such as the SPH. This may have deleterious repercussions in aeronautics when pilots have to localize external objects relative to earth-based directions in darkened environments.

Keywords: Spatial perception; Body orientation; Geocentric; Egocentric; Cognitive information

The perception of spatial orientation has been studied for decades, mainly through the influence of multiple sensory information, such as visual, vestibular and somatosensory cues available to the observer. However, recent literature provided growing evidence that cognitive factors may have a significant implication in spatial perception.

In this context, several studies focused on the role of subjective expectations in perceptual judgements about orientation in space. For instance, Lackner and DiZio [11] showed that sensations of body inversion in microgravity seem to depend on cognitive factors including anticipated or expected orientation with respect to the aircraft cabin. On earth, when subjects have prior knowledge of the type of linear motion to which they are exposed in darkness, they never exhibit any sensation of body tilt, contrary to what can happen when subjects are unaware of how they are moved [19]. This observation might be due to a cognitive suppression of tilt sensation when the displacement is known and expected. Conversely, mental imagery of a visual motion is able to facilitate the perception of a roll-vection displacement [12]. The perception of a geocentric direction, such as the subjective visual vertical has also been found to be significantly influenced by mental imagery [13,14] and by other cognitive components, such as the presence of a meaningful visual frame (e.g., a circular clock whose numbers were displaced [7]).

Not only subjective expectations but also external feedback (FB) provided by the experimenter can modify spatial perception. Earlier studies investigating factors of adaptation to prismatic displacements emphasized the influence of conscious correction strategies based on the relevant given information [18]. For instance, making subjects aware of the visual space shift by providing them explicit information about prisms distortion led to reduced levels of adaptation [10,17]. However, by investigating the effect of erroneous FB in a spatial context, Brosvic and Finizio [5] showed that if accurate FB may markedly reduce the magnitude of the Müller-Lyer illusion, inaccurate FB does not necessarily deteriorate judgements by the same amount of the FB itself.

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The following experiment aimed at investigating whether an external erroneous FB about body tilt magnitude can modify the perception of the Subjective Proprioceptive horizon, compared to a condition in which an accurate feedback is provided. The SPH can be considered an estimated geocentric direction as subjects have to set their extended arm normal to gravity for achieving the task [2,3,9]. The originality of the present study was then to question the influence of different types of external conscious information about body orientation upon the judgement of a geocentric direction of space.

Eight right-handed healthy subjects (four males and four females; mean age: 25 ± 3.6 years) took part in the experimental sessions. None of the subjects had any known history of vestibular or somatosensory disorders and they all provided informed consent prior to testing according to the local ethic committee guidance and to the Helsinki convention.

Subjects were seated on a tilting servo-controlled apparatus allowing slow rotations in pitch (Fig. 1; for a more detailed description, see Bourdin et al. [2]). The axis of rotation was located 60 cm behind subjects' back, 20 cm lower than their hip level. Position signals from the tilting apparatus were sampled at 20 Hz (12 bit A/D converter). An enslaved position and velocity system enabled to reach an accuracy of $\pm 0.005°$. Subjects were tightly restrained with harness-type safety belts and their head was firmly stabilized by means of strap restrains. A rigid gutter placed around the elbow joint with straps maintained subjects' right arm extended. The SPH measurements were performed using an inclinometer (Accustar© no. 0211002), which was held at the level of the lateral epicondyle of the humerus to record arm position with respect to gravity. It reached a range of $\pm 60°$ and a resolution of $\pm 0.001°$ for a response frequency of 0.5 Hz.

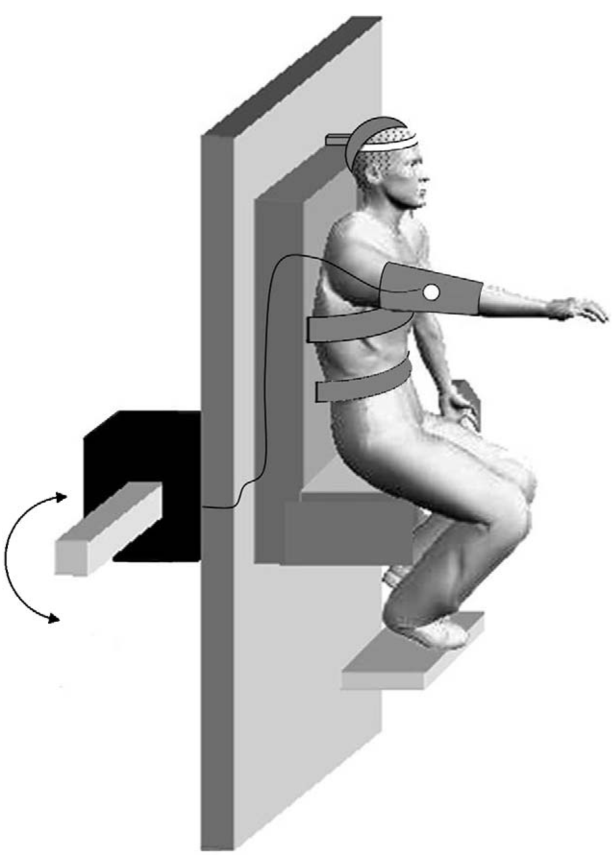

Fig. 1. Schematic representation of the experimental setup. The tilting apparatus enables to perform backward and forward body tilts at several velocities. Subjects were strongly attached with head, shoulders, hips and feet belts, to prevent any movement.

Two experimental sessions were randomly presented to the subjects. Both involved two successive episodes, a familiarization phase and a testing phase. During the familiarization phase, subjects were oriented at each angle of tilt manipulated during the subsequent testing phase. A constant velocity of $2° s^{-1}$ was used to reach, respectively, 3°, 6°, 9° forward (FOR) and 3°, 6°, 9° backward (BACK) tilts, at which the tilting apparatus stopped for 10 s. Subjects were informed about the real tilt magnitude at each angle of tilt. They were told to concentrate on the conscious sensations they would feel in the final static tilt rather than on the dynamics of tilt (as different patterns of rotation were manipulated in the subsequent testing phase). During the testing phase, each trial proceeded as follows: subjects were first positioned at a desired body orientation; then, they received an external FB about their body orientation, and finally, they were asked to judge their SPH by setting their right extended arm normal to the direction of gravity. Forty judgments were collected per subjects in the experiment. Seven body orientations (0°; 3° FOR, 6° FOR, 9° FOR and 3° BACK, 6° BACK, 9° BACK tilts) were presented and three tilt velocities (0.1°, 0.5°, $4° s^{-1}$, with initial accelerations above the semi-circular canal threshold for rotation perception [1]) were randomly manipulated to avoid time cues for tilt perception. Verbal external FB about the magnitude of body tilt was provided by the experimenter once subjects' tilt was stabilized. This FB was either true or false. In case of false FB, provided only at 6° FOR and 6° BACK physical body tilts for half of the trials, a "directional bias" was induced, with a magnitude of either 3° *forward* or 3° *backward.* A *forward* bias corresponded to a 6° BACK physical tilt announced "3° BACK" or to a 6° FOR physical tilt announced "9° FOR". A *backward* bias corresponded to a 6° BACK physical tilt announced "9° BACK", or to a 6° FOR physical tilt announced "3° FOR". True FB was provided for the other half of the trials at 6° FOR and 6° BACK of physical body tilt and for the rest of tilts manipulated in the testing phase. Table 1 summarizes the organization of trials presented in the experiment. Once the physical tilt was reached, subjects were kept immobile during 20 s, allowing the semi-circular canal effects to settle down [8], with their right arm aligned with the trunk. Then, they were asked to adjust their SPH by setting their right extended arm horizontally (i.e., normal to gravity) and to keep it in position for 3 s before turning back to the starting position. The tilting apparatus was brought back to the vertical after each SPH judgement at random constant velocities (0.1°, 0.5°, $4° s^-1$) and the room was enlightened until the next trial. Throughout the experiment, none of the subject consciously perceived any bias in the given external FB.

A six body tilts (3° FOR, 6° FOR, 9° FOR, 3° BACK, 6° BACK, 9° BACK tilts) × three velocities (0.1°, 0.5°, $4° s^{-1}$) analysis of variance (ANOVA) with repeated measures on all factors was performed on SPH estimates when true FB about body orientation was provided. It showed a main effect of the angle

Table 1
Number of trials (SPH estimates) for each body orientation

Body orientation	9 deg FOR	6 deg FOR	3 deg FOR	0 deg	3 deg BACK	6 deg BACK	9 deg BACK
Number of trials relative to real tilt	3 3 velocities × 1 [true] FB × 1 repetition	12 3 velocities × 1 [true] FB × 2 repetitions + 3 velocities × 2 [false] FB × 1 repetition	3 3 velocities × 1 [true] FB × 1 repetition	4 1 [true] FB × 4 repetitions	3 3 velocities × 1 [true] FB × 1 repetition	12 3 velocities × 1 [true] FB × 2 repetitions + 3 velocities × 2 [false] FB × 1 repetition	3 3 velocities × 1 [true] FB × 1 repetition
Number of trials relative to announced tilt	6	6	6	4	6	6	6

The purpose of this repartition is to generate the same number of trials for each magnitude of *announced* tilt.

of tilt ($F(5,35) = 10.64$, $p < 0.001$), but no effect of tilt velocity ($p = 0.40$) and no interaction between the two factors ($p = 0.16$). Furthermore, a regression analysis yielded a significant linear relationship between the angle of tilt and SPH estimates when subjects received veridical information about the magnitude of their body tilt (Fig. 2). Indeed, when a true FB was provided, SPH settings appeared significantly lower when subjects tilted forward and conversely higher when subjects tilted backward than when they sat upright.

A second step consisted in comparing SPH judgements achieved under true and false FB conditions. A two body tilts (6° FOR and 6° BACK) × three conditions of external FB (no bias condition for which correct FB about body tilt magnitude was provided; false FB condition inducing a *forward* bias; false FB condition inducing a *backward* bias) ANOVA was performed on SPH estimates. Results showed a main effect of the angle of tilt ($F(1,7) = 14.30$, $p < 0.01$; Fig. 3). SPH estimates appeared significantly lower at 6° FOR physical body tilt than at 6° BACK physical body tilt, whatever the FB condition. In addition, the ANOVA yielded a main effect of FB condition ($F(2,14) = 4.59$, $p < 0.05$): SPH settings appeared significantly higher in the *forward* bias condition when compared to the *backward* bias condition ($p < 0.05$; Newman–Keuls post hoc test; Fig. 3). The interaction between the two factors was not significant ($p = 0.37$).

Two main findings emerged from the present experiment. First, we found a clear linear effect of body tilt on SPH estimates when true external FB about the magnitude of tilt was provided to the subjects. This influence of body orientation is in line with many studies involving geocentric judgements, such as

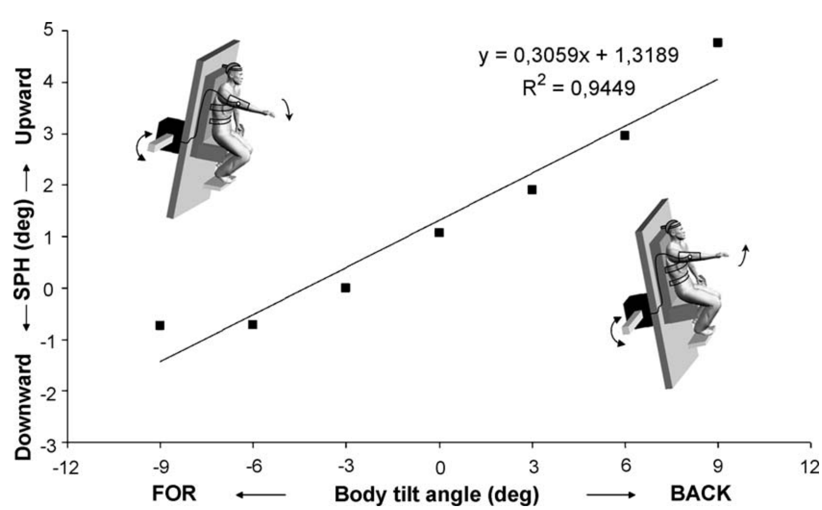

Fig. 2. Mean SPH as a linear function of whole-body tilt, when subjects received a true FB about the magnitude of their body tilt (i.e., no bias condition). Negative angles of tilt corresponded to forward tilts (FOR), whereas positive angles of tilt corresponded to backward tilts (BACK). Negative SPH values indicate settings below physical proprioceptive horizon whereas positive SPH values indicate settings above physical proprioceptive horizon. Sketches show the direction of the "body tilt effect".

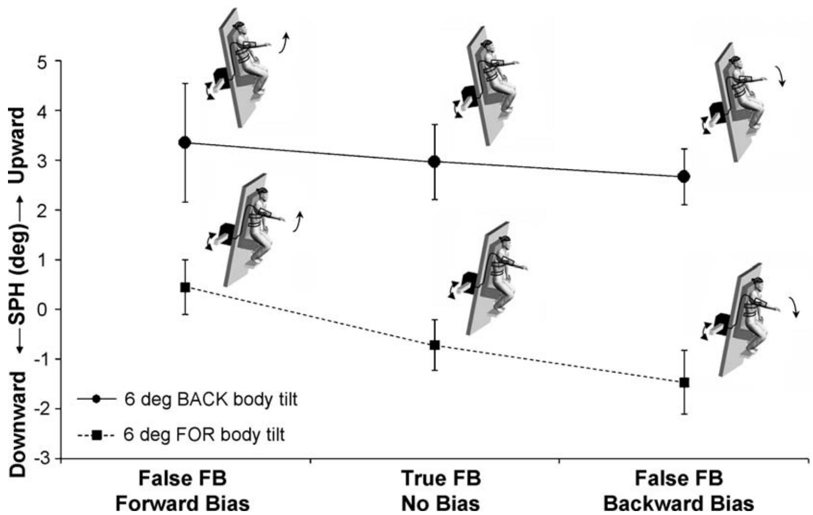

Fig. 3. Mean SPH estimates and standard errors recorded at 6° BACK and 6° FOR physical body tilts for different conditions of external feedback about body tilt magnitude. The *forward* bias condition corresponds to a false external information given by the experimenter about body orientation with a −3° forward error (e.g., 6° BACK physical tilt announced “3° BACK”, or 6° FOR physical tilt announced “9° FOR”). The *backward* bias condition corresponds to a false external feedback about body orientation with a +3° backward error (e.g., “6° BACK” physical tilt announced “9° BACK”, or 6° FOR physical tilt announced “3° FOR”). The no bias condition (which can be viewed as a baseline) corresponds to a true external feedback about body tilt. Sketches show the direction of the “Feedback effect”.

the subjective visual vertical in roll tilts (i.e., A-Effect, [4,15,20]) or the gravity referenced eye level in pitch tilts [3]. This effect could be explained by an “egocentric attraction” upon geocentric estimates exerted by the longitudinal *Z*-axis as a reference for verticality (i.e., idiotropic vector hypothesis [15]). Bourdin et al. [2] already showed a similar effect of body tilt upon SPH estimates when up to 8° slow body tilts were achieved without external FB. Strikingly, the slope of the linear regression line, reflecting the importance of the body tilt effect, was almost comparable in both studies (0.31 versus 0.34 in Bourdin et al.’s study). This may indicate that the knowledge of the magnitude of body tilt, when veridical, does not help subjects to successfully compensate for the egocentric attraction exerted by a physical tilt.

The second main finding of the present experiment was that false cognitive information provided to the subjects about their body orientation may yield repercussions on their perception of the geocentric environmental space. We found indeed a significant effect of the nature of the external FB relative to the magnitude of body tilt on SPH settings. When a *forward* bias in external FB was induced (i.e., when the magnitude of body tilt was actually announced 3° forward relative to the physical tilt), SPH was consequently set higher than in the *backward* bias condition. Although subjects were totally unaware of the incongruence between physical tilt and external FB, they partially compensated for the externally induced over- or under-estimation of tilt in their SPH estimates. In other words, when subjects were “induced” to feel more tilted forward than they actually were, the upward arm movement they need to do for setting their SPH exceeded in magnitude the one they would perform if they were induced to feel less tilted. This demonstrates that subjects took into account erroneous cognitive information about body tilt in their SPH judgements. Previous works already emphasized the role of erroneous external FB in sensorimotor [6,16] or in spatial perception [5,21] tasks, but they manipulated sensory sources as biased information and the provided FB essentially related to the measured variable. In the present experiment, we demonstrated that a biased verbal FB about body orientation might indirectly affect the perceived geocentric space. However, one must notice that the “amount” of cognitive bias was not fully taken into account in the SPH judgement. For instance, a +3° *forward* bias did not induce a +3° *upward* SPH setting, the ratio between FB bias and its repercussions on SPH estimates being less than one third in average. This is in line with results from Brosvic and Finizio [5], who showed that inaccurate FB about the Müller-Lyer illusion is not fully taken into account by the central nervous system to reach the intended adaptation.

Nevertheless, the present study clearly showed that subjects can be deleteriously influenced by wrong cognitive information about body tilt in judging a geocentric direction of space, such as the SPH. This may have important repercussions in aeronautics when pilots have to judge the position of external objects relative to earth-based directions in darkened environments.

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