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Semi-automatic measurement of visual verticality perception in humans reveals a new category of visual field dependency

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Abstract

Previous assessment of verticality by means of rod and rod and frame tests indicated that human subjects can be more (field dependent) or less (field independent) influenced by a frame placed around a tilted rod. In the present study we propose a new approach to these tests. The judgment of visual verticality (rod test) was evaluated in 50 young subjects (28 males, ranging in age from 20 to 27 years) by randomly projecting a luminous rod tilted between -18 and +18° (negative values indicating left tilts) onto a tangent screen. In the rod and frame test the rod was displayed within a luminous fixed frame tilted at +18 or -18°. Subjects were instructed to verbally indicate the rod's inclination direction (forced choice). Visual dependency was estimated by means of a Visual Index calculated from rod and rod and frame test values. Based on this index, volunteers were classified as field dependent, intermediate and field independent. A fourth category was created within the field-independent subjects for whom the amount of correct guesses in the rod and frame test exceeded that of the rod test, thus indicating improved performance when a surrounding frame was present. In conclusion, the combined use of subjective visual vertical and the rod and frame test provides a specific and reliable form of evaluation of verticality in healthy subjects and might be of use to probe changes in brain function after central or peripheral lesions.

Key words: Rod test; Rod and frame test; Subjective visual vertical; Visual streams; Two-alternative forced-choice task

Introduction

Under normal circumstances, we are able to use vision to precisely align objects with the gravitational vertical without any other reference frame. This capacity is named subjective visual vertical (SVV), and can be assessed by presenting a long luminous rod tilted at different angles in complete darkness to an upright sitting subject (1). For the past 50 years, many investigators have been interested in assessing the perception of verticality in control subjects and in a variety of patients to probe changes in brain function after central or peripheral lesions (2-8). Taken together, the results of such studies suggest that altered SVV may be one of the factors underlying the difficulties that hemiplegic patients experience in keeping their balance after a recent stroke (3,4,7), which possibly is due to an abnormal internal representation of verticality (9).

In their original studies, Witkin and Asch (10,11) designed another test to assess the influence of surrounding oriented contours on the perception of verticality. This test, which became known as the rod and frame test (RFT), involved asking subjects to judge the inclination of a rod placed at the center of a tilted rectangular frame. On the basis of RFT, normal subjects were classified either as "field dependent" (FD), when the presence of the frame exerted a significant influence on the judgment of rod tilt, or as "field independent" (FI), when the presence of the frame did not interfere with the judgment of verticality. A third category, known as "field intermediate" (FInt), was used for subjects for whom the presence of the frame exerted some influence

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albeit to a lesser degree than the FD group and more than FI subjects (10,11).

Later on, Leventhal and Sisco (12) claimed that FD subjects essentially rely on external visual cues and have difficulties in separating the target from the environment to perform the task, whereas FI subjects rely more on internal references provided by proprioceptive and vestibular inputs. Interestingly, reports on RFT after central and peripheral lesion revealed that peripheral vestibular patients present an ipsilaterally biased judgment of RFT, tending to be more FD than normal subjects (13). Bonan et al. (6) also found a general shift towards FD in acute stroke patients. In all these studies the volunteers had to manually adjust a luminous bar presented at different inclinations towards what they considered as vertical. Computer-based versions of the rod and frame test for verticality perception have been recently developed (9,14,15). However, in this set of experiments, the task also consisted of adjusting the luminous bar to a visual vertical reference.

A particularly useful and reliable method for eliciting responses from a person about his or her experiences with a stimulus is the two-alternative forced choice (TAFC) task (16,17). Compared to other common psychophysical methods (e.g., adjustment and yes-no tasks), TAFC is considered to be less prone to subject response bias, thereby insuring better predictive validity of the measured sensory capacity. For example, Blackwell (16) has found that increment thresholds obtained by forced choice were significantly smaller than those obtained with a yes-no procedure. Thus, we reasoned that this methodological approach might be useful in the domain of verticality judgment to help refine threshold estimates.

The aims of this study were 1) to validate, in an expressive number of healthy subjects, a revisited version of SVV and RFT based on a TAFC task protocol, and 2) to explore how SVV and RFT relate to each other in the judgment of visual verticality, using a novel experimental approach.

Material and Methods

Fifty volunteers (28 males), ranging in age from 20 to 27 years (mean = 24.78 years; SD = 3.9 years), with no history of motor problems, neurological diseases or known sensory deficits were recruited and submitted to the visual assessment protocol described below. All subjects gave written informed consent to undergo the experimental procedures and to participate in the study, in accordance with the Helsinki declaration. The project was approved by the Ethics in Research Committee of the Hospital Universitário Clementino Fraga Filho, Federal University of Rio de Janeiro (UFRJ).

Visual assessment

Subjects sat comfortably in a chair without any instruction to maintain a specific body posture, in complete darkness with their head fixed by a forehead support, and facing the center of a tangent semitransparent black curtain (2.0 x 2.0 m) placed at a distance of 90 cm. Stimuli were back-projected onto the screen via a liquid crystal display (LCD) video projector (VPL-ES1, Sony), and were presented with timing accuracy using the ActiveStim software (www.activestim.com) controlled by a customized program written in Labview (National Instruments, USA). Each stimulus condition was repeated five times and lasted 5 s. Subjects were instructed to indicate if the rod was tilted to the left or to the right of an imaginary vertical line (TAFC). After a few training trials, the experiment started and the verbal response per stimulus condition was collected by the experimenter.

In the SVV, stimuli consisted of a high-contrast bar (length: 9.5°; line thickness: 0.31°) tilted from -18 to +18° (-18, -16, -14, -12, -10, -8, -6, -4, -3, -2, -1, 0, 1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, with negative values indicating left tilts), for a total of 23 conditions that were presented in pseudorandom order. In the RFT, rod stimuli were surrounded by a frame of equal contrast (height: 28.1°; width: 19.6°; line thickness: 0.31°), tilted at either +18 or -18° (18).

Data analyses

Analyses were performed using the Excel/Microsoft Office 2003 software (Microsoft®), by calculating for each subject the area under the curve (trapezium rule) formed by the amount of errors across conditions and for both tests. This methodology resulted in six different values, two referring to the rod test (one for the left rod tilt, RTl, and one for the right rod tilt, RTr) and the remaining four referring to the RFT. The "congruent" situation consisted of the condition where rod and frame were tilted to the same side (RFTcl and RFTcr) and the "incongruent" situation consisted of the condition where rod and frame were tilted to opposite sides (RFTil and RFTir). To determine if the surrounding frame of reference influenced the perception of the visual vertical, area values were compared by repeated measures analysis of variance (ANOVA) using the Statistica 6.0/2001 software (StatSoft®). Statistical significance was determined by means of the *post hoc* Tukey test with a criterion level of rejection of 0.05.

A visual index was devised in order to merge the pattern of correct responses collected for both SVV and RFT into a single value. It was calculated as follows: Initially, the number of correct responses per condition of rod angulation was multiplied by the absolute value of the corresponding angle. The weighted sum obtained for each condition yielded one value for SVV and two values for RFT (one to the right and the other to the left). Two component visual indices were then determined, one incorporating all conditions with a rightward inclination of the frame (VIr), and the other incorporating all conditions with a leftward inclination (VIl) (Equation 1):

$$VIr = \frac{(RT - RFTr)}{(RT + RFTr)} \quad VIl = \frac{(RT - RFTl)}{(RT + RFTl)} \quad \text{(Eq. 1)}$$

The final visual index was defined as:

$$VI = \frac{VIr + VIl}{2}\ x\ 100 \quad \text{(Eq. 2)}$$

Based on the visual index, high positive values would be the consequence of more correct guesses in SVV than in RFT, which is typical of FD subjects. Similar amounts of correct guesses for SVV and RFT would characterize FInt subjects, devoid of a preferential strategy in the assessment of verticality. Similar amounts of correct guesses for SVV and RFT, but presenting a greater number of correct guesses in RFT than the intermediate subjects would characterize FI subjects. Finally, negative values, FI(-), might characterize the class of individuals for whom the amount of correct guesses for RFT exceeds that for SVV.

Results

The mean percentage of errors plotted as a function of stimulus tilt is plotted in Figure 1. ANOVA of area under the curve measures revealed that subjects made more errors in congruent than in incongruent situations (F (5.240) = 21.02, P < 0.01). *Post hoc* analysis (Figure 2) showed that RFT congruent situations (RFTcl and RFTcr) differed significantly both from incongruent situations (RFTil and RFTir) and from RTl and RTr (P < 0.01). Neither gender nor tilt side effects were found.

The visual index value, conceived as a means to capture each volunteer's visual verticality profile by combining SVV and RFT, is plotted in Figure 3. Individual performance spread from -3 to +23 visual index units. Whereas a large number of subjects ranged in intermediate index values (similar amounts of correct guesses for SVV and RFT), a small percentage of subjects showed high index values as a consequence of more correct guesses in SVV than in RFT, and were thus classified as FD. A third group of subjects presented similar amounts of correct guesses for SVV and RFT, but with a greater number of correct guesses in RFT than the intermediate subjects and were identified as FI. Finally, for a small portion of our sample, the amount of correct guesses for RFT exceeded that for SVV, resulting in negative index values. The mean percentage of errors plotted as a function of stimulus tilt for FD and FI subjects is shown in Figures 4 and 5, respectively.

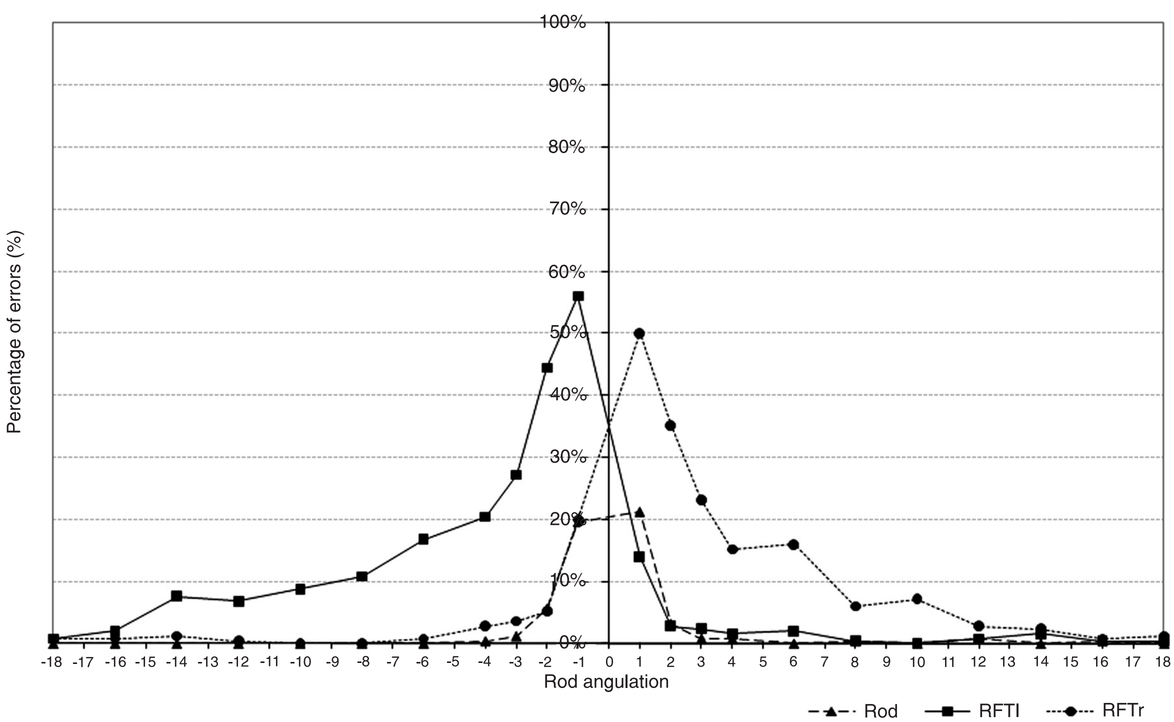

Figure 1. Percentage of errors per rod angle in SVV and RFT. N = 50. SVV = subjective visual vertical; RFTl = rod and frame test, frame tilted to the left; RFTr = rod and frame test, frame tilted to the right.

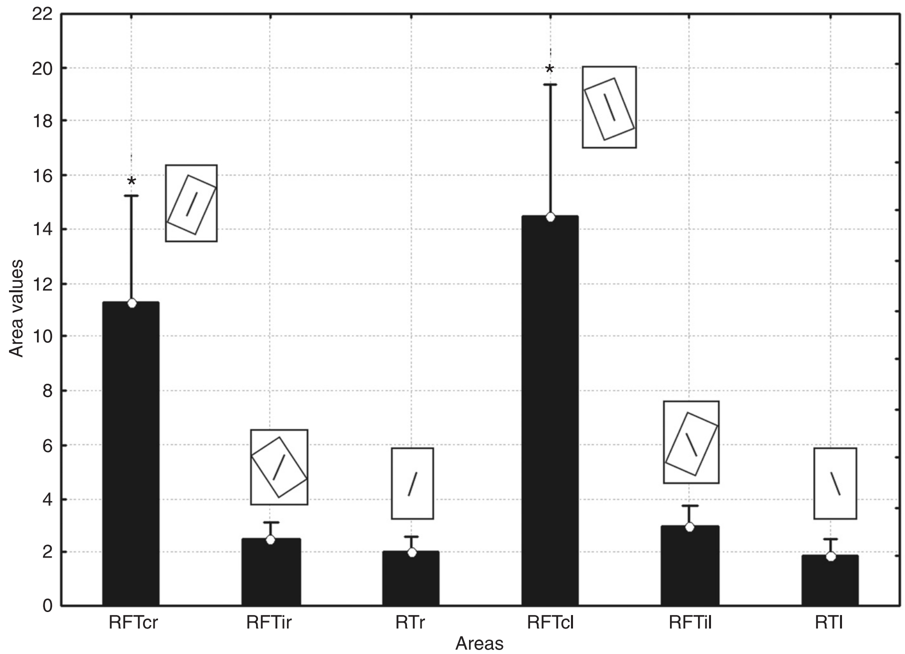

Figure 2. Area under the curve obtained in the rod test (RT) and rod and frame test (RFT). RFT congruent situations (RFTcl and RFTcr) differed significantly from both incongruent situations (RFTil and RFTir) and RTl and RTr; l = left; r = right (repeated measures ANOVA, *post hoc* Tukey test, P < 0.01).

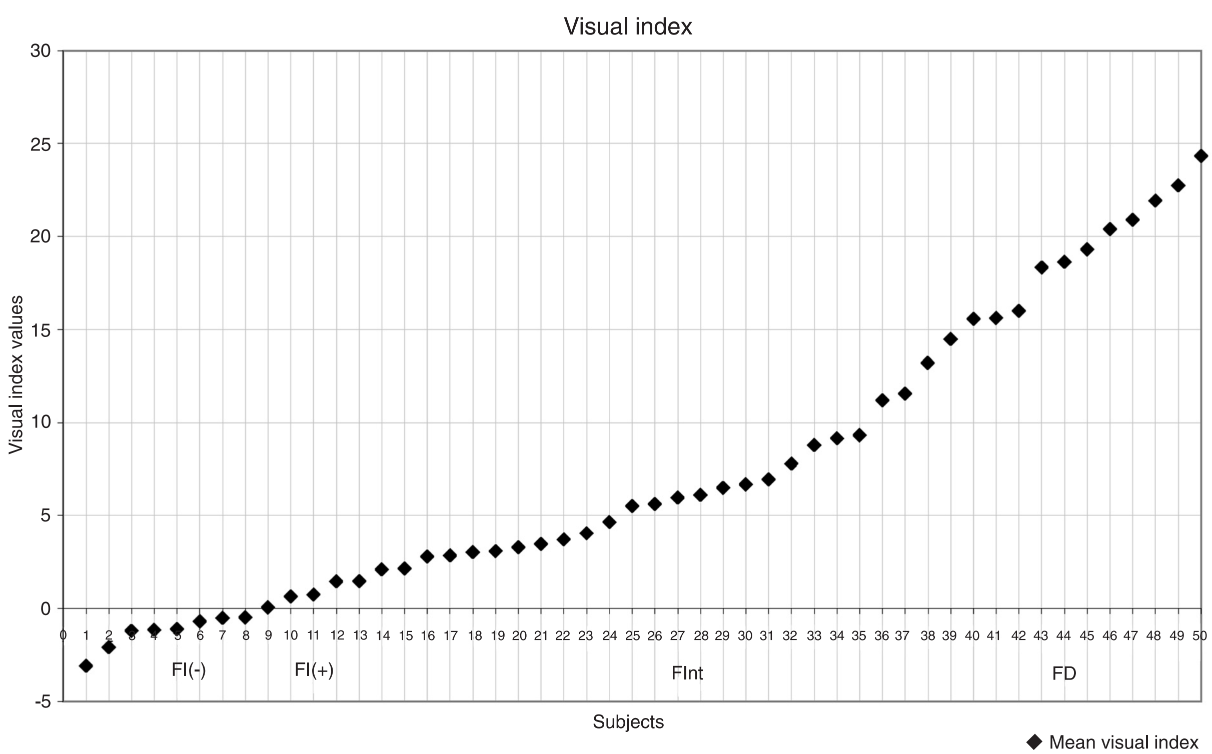

Figure 3. Distribution of visual index. FI(-) = field-independent negative values; FI(+) = field-independent positive values; FInt = field intermediate; FD = field-dependent values.

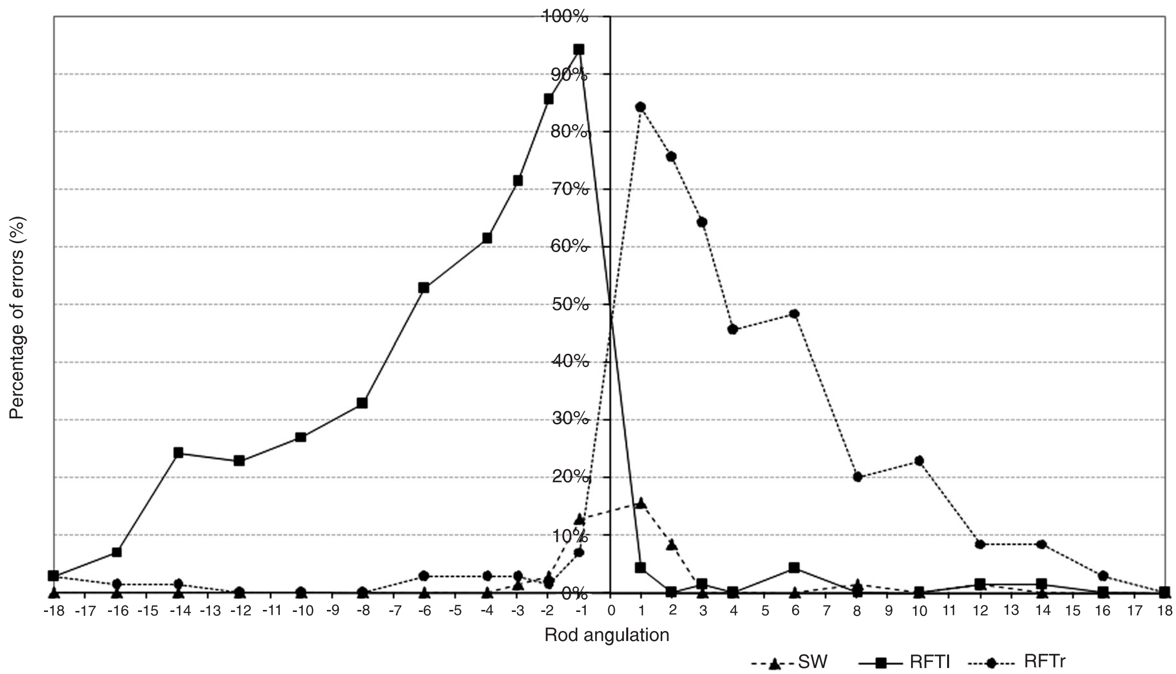

Figure 4. Percentage of errors per rod angle in SVV and RFT in field-dependent (FD) subjects (N = 14). SVV = subjective visual vertical; RFTl = rod and frame test, frame tilted to the left; RFTr = rod and frame test, frame tilted to the right.

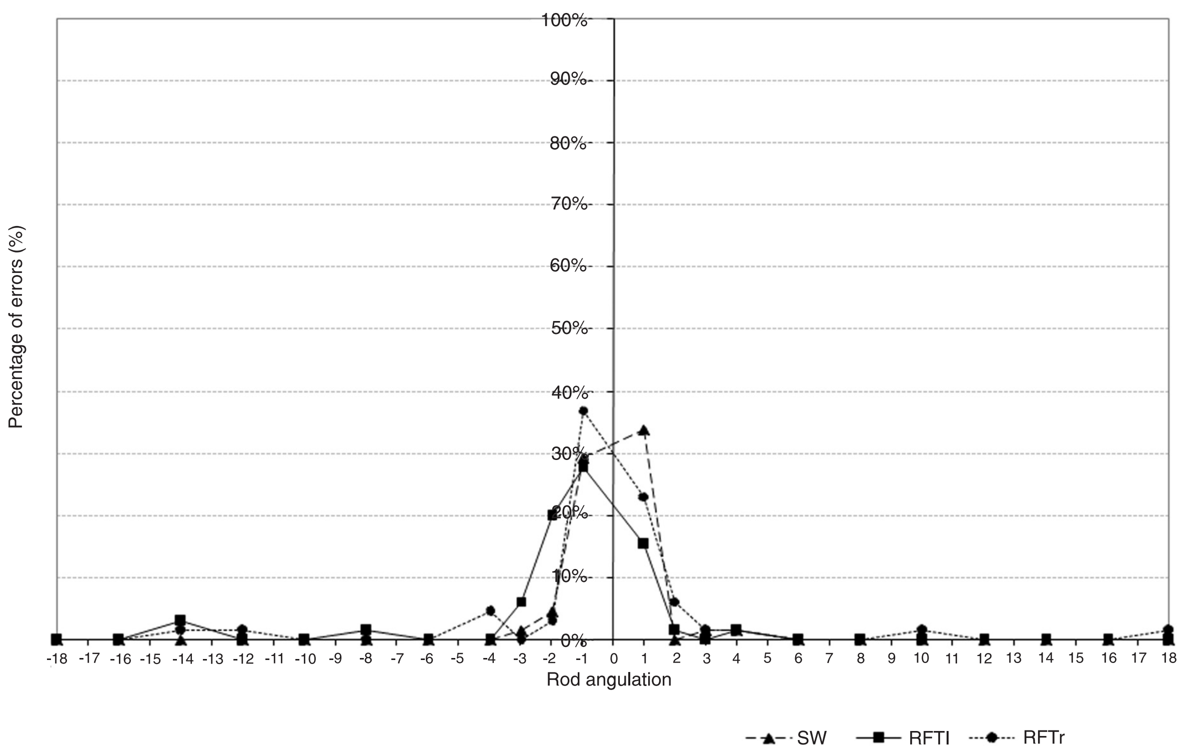

Figure 5. Percentage of errors per rod angle in SVV and RFT in field-independent subjects (N = 14). SVV = subjective visual vertical; RFTl = rod and frame test, frame tilted to the left; RFTr = rod and frame test, frame tilted to the right.

Discussion

Demonstrating the reliability of the methodology employed in the present study, we replicated here the findings of Asch and Witkin (1) by showing that normal subjects are able to make accurate judgments of absolute rod inclination. However, when the rod was surrounded by a frame with the same inclination (congruent situation), a large number of errors in the judgment of verticality was observed. This effect had also been demonstrated in previous studies (11,12,19,20). A distinguishing aspect of our approach is that it relies on a “forced choice” design in conjunction with a method of constant stimuli. An advantage of this approach is that it tends to minimize the response biases and stimulus history effects often associated with other procedures such as the method of adjustment that has been used by Asch and Witkin for testing verticality perception. Early studies by Werner and Wapner (21) showed that the initial position from which the rod is moved can significantly affect the estimation of its final position. This bias was solved in our study by presenting the tilted visual stimuli randomly instead of sequentially. In classical SVV and RFT studies, a mechanical-manual device was commonly employed to evaluate verticality. In most of these studies (1-8,10-12) subjects were required to manually align the rod with respect to their subjective vertical, eventually leading to confounds between visual and proprioceptive (haptic) inputs. To prevent proprioceptive cues from contaminating visually based verticality judgments, we chose a verbal forced-choice paradigm in which the stimuli were presented in a semi-automatic manner thus allowing precise angulations of the rod tilt without any manual intervention (although other potential sources of proprioceptive cues stemming from subject’s body posture are known to modulate visual dependency) (22-24). Furthermore, we took advantage of the fact that increment thresholds obtained by forced choice can be significantly smaller than those obtained with a yes-no procedure (16). Thus, for the first time both SVV and RFT were performed within steps of 1° and 2° and by employing a high number of trials.

The large number of errors observed in situations where rod and frame are tilted to the same side (congruent condition) may be due to a perceptual illusion. Bridgemen et al. (25) reported that when a fixed visual target is surrounded by a large laterally shifted frame, subjects indicate that the target consistently appears to shift in a direction opposite to that of the frame. In other words, our perceptual system is designed to deal with the relative location of a stimulus within the visual array rather than with its absolute location (26,27). Thus, the subjects’ perceptual illusion of assigning a displacement to the target and not to the frame, once the latter has moved (25,27), may explain the large amount of errors detected in the congruent situations of rod (target) and frame and the virtual absence of errors in the incongruent situation. A negative visual frame effect was also reported in RFT (15,23). In this case, subjects see the rod tilted in the opposite direction to that of the frame. This effect was interpreted as overcompensation for a misleading frame tilt: The subject knows she is misled by the frame tilt, but cannot estimate by how much, as she has difficulties in transferring to non-visual cues for orientation (23). In addition, these negative visual frame effects are more frequently observed in 2-D RFT devices than in 3-D ones (15).

As pointed out in 1948 (11) and as will be discussed below, a closer look at individual behavior reveals that a given subject can be more or less influenced by the presence of this surrounding frame. The significant scatter observed regarding field dependence/independence might be explained in part by the relative load contribution of each sensory modality (visual, vestibular and somatosensory) in the judgment of verticality (28). One possibility is that field dependence variability might be due to the use of distinct visual stream processing strategies to perform the task (29). According to this hypothesis, FD subjects would base their judgments on the perceptual content mediated by the ventral stream. Strongly connected to memory systems, this visual stream is known to be easily “fooled” by visual illusions (30). In contrast, FI subjects would rely predominantly on processing from the dorsal stream, which serves the much more immediate function of guiding our actions from moment to moment (30) and might therefore be more directly involved in the construction of vertical posture (9). It is important to emphasize that the mechanisms mediating the perception of object location operate largely in allocentric coordinates (ventral stream), whereas those mediating the control of object-directed actions operate in egocentric coordinates (dorsal stream) (31).

In a similar perspective, Isableu et al. (19,20) postulated that FD and FI subjects might have distinct strategies of body segmental stabilization: while FD subjects would rely on visual cues and employ an *en bloc* strategy of segmental stabilization, FI subjects would exhibit a more modular segmental stabilization, with head, shoulder and hip moving independently from each other during stance control. Such results have reinforced the idea of a close relationship between visual dependency as tested by SVV, body coordinates and postural control. In this context, visual dependency could result from a difficulty ‘or neglect’ to exploit proprioceptive cues and, more particularly, kinesthetic cues related to body mass and inertia (32-34).

The visual index, devised herein as an objective measure of SVV/RFT, revealed a range of positive and negative values which, based on the above considerations, may be interpreted as follows: 1) high positive values are the consequence of more correct guesses in RT than in RFT, which is typical of FD subjects. Such individuals would tend to use visual cues to a larger extent, basing their judgment on an external, preferably allocentric reference; 2) similar amounts of correct guesses for SVV and RFT would characterize FInt subjects, devoid of a preferential strategy in the assessment of verticality; 3) similar amounts of correct guesses for SVV and RFT, but presenting a greater number of correct guesses in RFT than the intermediate subjects would characterize FI subjects. Such individuals would tend to use internal cues, preferably basing their judgments on an egocentric reference; 4) negative values, FI(-), might be used to characterize a new (4th) class of individuals for whom the amount of correct guesses for RFT exceeds that for SVV, thus indicating FI subjects who tend nevertheless to improve their performance when a frame is present. The existence of this group might suggest an inverse effect of the frame illusion, maybe auxiliary in the perception of verticality.

Previous reports on RFT after central and peripheral lesions have revealed that peripherally impaired vestibular patients present an ipsilaterally biased judgment of RFT, tending to be more FD than control subjects (13). Bonan et al. (6) have also found a general shift towards FD in acute stroke patients. Taken together, these results might indicate that brain representations corresponding to the egocentric reference frame are more affected by such conditions. However, further study is necessary to unveil the brain circuits underlying FD and FI, and how they relate to SVV and RFT in stroke patients.

The present study provided a new version of SVV and RFT by employing a TAFC task and offered a means to calculate a visual index. This index allowed the identification of a sub-category of subjects other than field dependent (those thought to rely on an allocentric frame of reference to judge verticality) and field independent (the ones who presumably make use of an egocentric frame of reference). This sub-category consists of field-independent subjects who scored a larger amount of failed guesses in RT than in RFT, indicating an improvement in performance caused by the surrounding frame. By extracting separate information from each rod inclination and in combination with rod and frame values, our visual index yields an estimate of how these two tests relate to each other. It might thus be of use in the clinical evaluation of brain lesion patients.

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