Correspondence

# We are most aware of our place in the world when about to fall

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When making orientational judgements, such as aligning picture frames or positioning for a golf swing, we maneuver rather than remaining immobile. This observation is at odds with many psychophysical studies of spatial orientation. Accurate perception of spatial orientation is of greatest importance when it is imperative to maintain precarious balance. It has been proposed [1,2] that, when balancing with respect to the gravito-inertial force vector (GIF), a subject gains information about orientation through actions and reactions (the 'dynamics of balance'). This guides the maintenance of equilibrium. We give the first experimental evidence that perception of the direction of the GIF does improve in a situation demanding a high level of balancing activity.

In the classic test of perception of visual orientation, a subject attempts to align a rod to the Earth vertical. If the rod is surrounded by a tilted rectangular frame to give misleading cues to verticality, observers tend to set the rod tilted in the direction of frame tilt [3,4]. This deviation from the true vertical is called the 'frame effect' and indicates the preferential dependence on visual cues. To test the 'dynamics of balance' hypothesis, we compared subjects' abilities to perform the rod and rod and frame tests (RFT) while standing at ease and while balancing on a narrow beam (Figure 1). When they balanced on the beam, our subjects set a rod within a tilted frame 27% more accurately to vertical (Supplemental Data). The accuracy of 'rod alone' settings, without a frame, was also improved.

This suggests that information from the 'dynamics of balance' improves the perception of orientation, underlining the aphorism that 'we are most aware of our orientation when about to fall'. As a corollary, the preferential dependence on a particular sensory channel can be modified by an orientation challenge. The precariousness provides the imperative to focus on establishing correct vertical orientation. Distraction or down-regulation of attention by the tilted frame, while retaining focus on the rod, could also reduce the impact of the frame tilt on the perception of orientation [5,6]. However, as 'rod alone' settings also improved with balancing, distraction of attention from the frame cannot be the only reason for the improved accuracy.

It would seem paradoxical that the perception of the Earth vertical improved while the postural sway increased during balancing, because the efferent and sensory feedback signals during complex balancing movements could be noisy and difficult to interpret. However, incorporation into perceptual estimates of verticality, together with visual cues, in a Bayesian combination of probabilities might be a way of refining perception [7,8].

To determine whether perception is influenced by the dynamics of balance we tested if RFT errors improved with an increase in balancing activity, from sitting, to standing, to balancing on a beam. The subjects (12 males, 16 females, average age 26.4 years, ranging from 20 to 54 years) set the rod to the perceived vertical position, with a frame present as well as with the rod alone visible (Figure 1). In each trial, with the subject's eyes closed, the experimenter positioned the frame tilted to left or right by 28° and/or set the rod in left or right tilt to a random angle of 25°–35° from the Earth vertical. The subjects opened their eyes, adjusted the rod to Earth vertical with a hand control, then re-closed their eyes. While on the beam, subjects held a safety handrail, let go and balanced while adjusting the rod to vertical, then regained hold of the handrail. Conditions were assigned according to William's Latin Squares balanced for order. For each sitting, standing or balancing condition, subjects performed 8 rod settings. Individual rod settings took 5–6 seconds.

As visual vertical estimates are usually obtained seated, a control study was performed to evaluate the comparative effect of stance on the rod and frame effect (RFE). Subjects (8 males, 13 females, average age 29.2 years (21–55 years)) performed rod settings against a tilted frame, sitting and standing (Figure 1). The order of presentation alternated between subjects and individual trials were conducted as for standing/beam-balancing described above.

In the main and control experiments, one third of the subjects set the rod tilted in the direction of the frame tilt (Supplemental Data), whereas one quarter of subjects set the rod tilted in the opposite direction, which we refer to as a 'negative frame effect'. The negative effect may be overcompensation for misleading frame tilt. The subject knows she is mislead by the frame tilt, but cannot estimate by how much, as she has difficulties in transferring to non-visual cues for orientation.

For the main experiment, the regression slope of RFT balancing was significantly less than unity (0.73 with 95% confidence intervals of 0.56–0.88). This shows that RFT estimates during balancing were less than during standing. A repeated measures analysis of variance (ANOVA) on RFT settings during standing at ease versus balancing and with 'rod alone' versus 'rod with frame' was performed on the absolute mean values. Subjects who, when standing at ease, had 'rod alone' or RFT settings of less than 0.3° from upright were excluded, leaving 19 subjects. Tilts of less than 0.3° are less than the absolute threshold of tilt

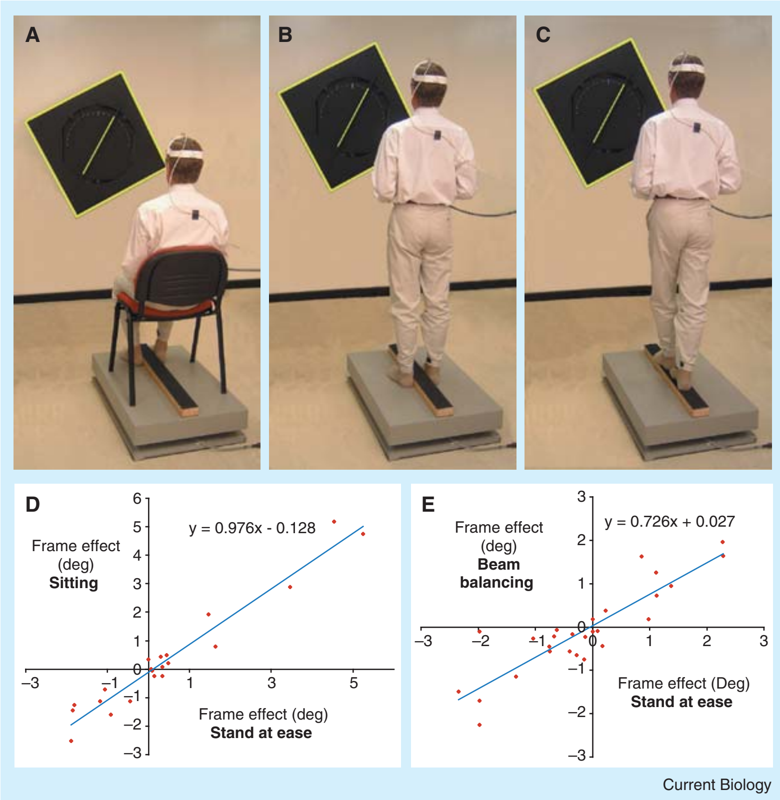


Figure 1. Comparison of estimate of visual vertical seen against a tilted frame for three levels of postural change.
(A–C) Subject facing a rod and square frame subtending 40° at 1.41 m: (A) sitting; (B) standing 'at ease'; (C) Standing on the beam 'balancing'. The beam was 86 cm long, 9 cm high and 4.5 cm wide and was mounted on a force platform transducing displacements of the center of pressure along the antero-posterior and lateral axes. Only the rod and frame periphery were illuminated in the experiment and the room was in darkness. For (B) and (C), head position in roll was measured using a Fastrak (Polhemus$^{TM}$). Single axis gyroscopes (Silicon Sensing Systems $^{TM}$) attached to the subject measured angular velocity in roll at (C7) and (L1). (D) Comparisons of Frame Effect for standing at ease and beam balancing ($R^2$ = 0.78, $n$ = 28) (E) Control experiment of standing at ease and sitting ($R^2$ = 0.944, $n$ = 21).

detection with our apparatus and were excluded to reduce variance and facilitate the sensitivity of the ANOVA. There was a significant reduction of 33% in RFT error when balancing was compared to standing and a marginal reduction in 'rod alone' error (variance ratio: F = 7.9; degrees of freedom: df = 1,18; $p$ = 0.012; see Supplemental Data). There were no interactions. A subsequent matched pair $t$-test between RFT settings during standing compared to balancing yielded a significant reduction in error ($n$ = 19, $t$ = 2.6, $r$ = 0.672, $p$ = 0.001), showing that the ameliorating effect of balance on RFT error is robust (Supplemental Data). 'Rod alone' setting error was improved by balancing for the 13 subjects who had the larger errors (>0.7°) when standing ($t$ = 2.4, $p$ = 0.034).

There was no difference in the mean frame effect between subjects performing the RFT standing at ease and sitting down (Figure 1). The slope of the balancing/standing (0.73) regression was significantly smaller than that of the sitting/standing (0.98) regression. This shows the specific ameliorating effect of balancing (Student's $t$-value: $t$ = 2.42; df = 44; $p$ = 0.02; 2 tailed) [9].

Sway at the level of platform, hip and shoulders increased by 200–600% during beam balancing, whereas head sway increased by only 60%, hence the tactic was preferentially to maintain the head relatively stable in space (Supplemental Data). There were no relationships between changes in sway measures from standing at ease to balancing and changes in the frame effect.

## Supplemental data

Supplemental data are available at http://www.current-biology.com/cgi/content/full/14/15/R609/DC1/

### References

1. Stoffregen, T.A., and Riccio, G.E. (1988). An ecological theory of orientation and the vestibular system. Psychol. Rev. *95*, 3–14.
2. Riccio, G.E., Martin, E.J., and Stoffregen, T.A. (1992). The role of balance dynamics in the active perception of orientation. J. Exp. Psychol. Hum. Percept. Perform. *18*, 624–644.
3. Witkin, H.A., and Ash, S.E. (1948a). Studies in space orientation III. J. Exp. Psychol. *38*, 603–614.
4. Witkin, H.A., and Ash, S.E. (1948b). Studies in space orientation IV. J Exp Psychol. *38*, 762–782.
5. Leibowitz, H.W., and Dichgans, J. (1980). The ambient visual system and spatial orientation. I Spatial orientation in flight, Current problems. Spatial orientation in flight: Current problems. Conf. Proc. *287*, Neuilly sur Seine, AGARD/NATO, *B4*, 1–4.
6. Wickens, C.D. (1992). Engineering Psychology and Human Performance, Second Edition. (Harper Collins NY), pp. 417.
7. Ernst, M.O., and Banks, M.S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. Nature *415*, 429–433.
8. Battaglia, P.W., Jacobs, R.A., and Aslin, R.N. (2003). Bayesian integration of visual and auditory signals for spatial localization. J. Opt. Soc. Am. A Opt. Image Sci. Vis. *20*, 1391–1397.
9. Baily, N.T.J. (1973). Statistical Methods in Biology (English Universities Press), pp. 183–184.

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