Gait & Posture 94 (2022) 1–8

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Priming overconfidence in belief systems reveals negative return on postural control mechanisms

Patricia Castro [a,b,c], Efstratia Papoutselou [a], Sami Mahmoud [d], Shahvaiz Hussain [a], Constanza Fuentealba Bassaletti [e], Diego Kaski [f], Adolfo Bronstein [a,*], Qadeer Arshad [a,g,*]

[a] *Neuro-otology Unit, Department of Brain Sciences, Imperial College London, London, UK*
[b] *Universidad del Desarrollo, Escuela de Fonoaudiología, Facultad de Medicina Clínica Alemana. Santiago, Chile*
[c] *Departamento de Fonoaudiología, Facultad de Medicina, Universidad de Chile, Santiago, Chile*
[d] *Fakultät für Medizin, Technische Universität München, München, Germany*
[e] *Escuela de Fonoaudiología, Facultad de Medicina, Universidad San Sebastián, Concepcion, Chile*
[f] *Department of Clinical and Motor Neurosciences, Centre for Vestibular and Behavioural Neurosciences, University College London, London, UK*
[g] *inAmind Laboratory, Department of Neuroscience, Psychology and Behaviour, University of Leicester, University Road, Leicester LE1 7RH, UK*

ARTICLE INFO

Keywords:
Postural control
Priming
Expectation
Postural instability

ABSTRACT

Background: Modulation of postural control strategies and heightened perceptual ratings of instability when exposed to postural threats, illustrates the association between anxiety and postural control.

Research question: Here we test whether modulating prior expectations can engender postural-related anxiety which, in turn, may impair postural control and dissociate the well-established relationship between sway and subjective instability.

Methods: We modulated expectations of the difficulty posed by an upcoming postural task via priming. In the *visual priming* condition, participants watched a video of an actor performing the task with either a stable or unstable performance, before themselves proceeding with the postural task. In the *verbal priming* paradigm, participants were given erroneous verbal information regarding the amplitude of the forthcoming platform movement, or no prior information.

Results: Following the visual priming, the normal relationship between trunk sway and subjective instability was preserved only in those individuals that viewed the stable but not the unstable actor. In the verbal priming experiment we observed an increase in subjective instability and anxiety during task performance in individuals who were erroneously primed that sled amplitude would increase, when in fact it did not.

Significance: Our findings show that people's subjective experiences of instability and anxiety during a balancing task are powerfully modulated by priming. The contextual provision of erroneous cognitive priors dissociates the normally 'hard wired' relationship between objective measures and subjective ratings of sway. Our findings have potential clinical significance for the development of enhanced cognitive retraining in patients with balance disorders, e.g. via modifying expectations.

1. Introduction

The scientific foundations of the postural control system were built upon work in decerebrated animals [1] Later, work in patients with CNS and peripheral sensory disorders were essential in understanding the input-output mechanisms governing postural control [2,3]. Postural maintenance, however, is not solely dependent upon sensory-motor loops, as significant contributions are provided by cognitive and emotional inputs. For example, increasing postural threat by raising the height of a standing surface generates anxiety and results in associated changes of postural control strategies (i.e. stiffened stance) [4,5], and modulation of perceptual ratings of instability [5,6].

Healthy individuals [7,8] and patients with neurological conditions [8] are able to accurately rate their perceived postural stability (i.e. how unsteady am I?), as illustrated by the fact that they tally well with objective measures of body sway. This logarithmic function linking objective instability (sway) and subjective instability (self-ratings) is robust [7,8]. It is conceivable that this robust relationship can be

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* Correspondence to: Academic Department of Neuro-otology, Division of Brain Sciences, Charing Cross Hospital Campus , London W6 8RF, UK.
E-mail addresses: a.bronstein@imperial.ac.uk (A. Bronstein), q.arshad@imperial.ac.uk (Q. Arshad).

https://doi.org/10.1016/j.gaitpost.2022.02.015
Received 29 October 2021; Received in revised form 1 February 2022; Accepted 13 February 2022

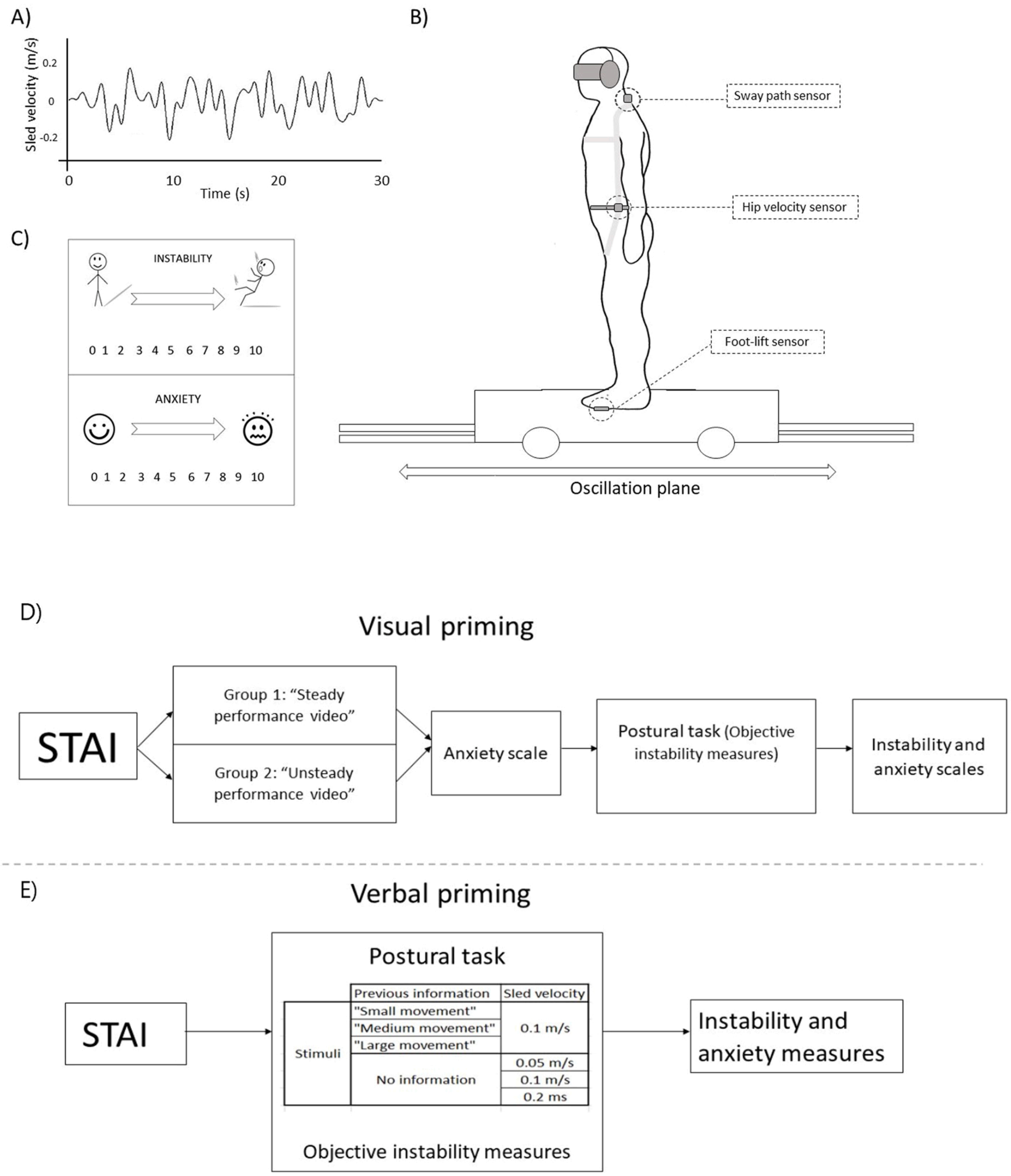

Fig. 1. A) Stimulus profile used to drive the sled. The stimulus contains 4 sinewaves of 0.18, 0.37, 0.69 and 0.9 Hz combined with a duration of 30 s resulting in pseudorandom perturbations with different maximum velocity. In this case the trace corresponds to the stimulus used in Experiment 1 which matches the sled amplitude "Large" from Experiment 2. B) Schematic representation of the postural task. Subjects stood on the platform parallel to the rail i.e. sled oscillations were perceived as back and forth. Subjects wore a blindfold and earmuffs to avoid distractions and a safety harness to prevent possible falls. Three body sensors were used to record body sway: Fastrak on the C7 vertebra to record Sway Path, Accelerometer on the right hip to record Hip Velocity and copper stripes on each foot sole to record foot-lifts from the platform. C) Cartoon aided scales to measure Instability and Anxiety. Both sheets were shown to subjects each time when asking their subjective rating. D) Flowchart of the procedure for the Visual priming experiment. E) Protocol used on experiment 2, Verbal priming.

modulated by emotional and cognitive factors. Such modulation in healthy individuals could be attributed to the aforementioned fear of falling [6], whereas in patients with functional (psychogenic) balance disorders it could be mediated by a dissociation between perceived body unsteadiness and actual (physical) body sway [9,10]. Such dissociation is in line with the theoretical framework suggested in the functional movement disorder literature that functional patients manifest a contextually inappropriate expectation that interferes with rational belief systems [11].

Here we propose to investigate whether the relationship between actual objective postural performance and subjective ratings of stability can be distorted in healthy individuals by introducing erroneous expectations (i.e. confidence) regarding the associated difficulty of an upcoming postural task. Accordingly, we assessed whether challenging belief systems by providing erroneous prior cues via priming, can lead to an expectational mismatch which, in turn, modulates postural control and distorts the normal relationship between objective measures of body displacement and subjective ratings of postural stability during random whole-body perturbations.

2. Material and methods

2.1. Participants

For the visual priming experiment, we recruited 30 healthy participants (12 females, age range: 19–36 yr). For the verbal priming experiment, we recruited a separate group of 30 individuals (17 females, age range: 18–35 yr). No subject had any current or past-history of vestibular, neurological, ophthalmological or psychiatric disorder, ensured with a pre-screening questionnaire. All participants provided written informed consent as approved by the local ethics research committee.

2.2. Postural task

Participants stood on a linearly oscillating sled powered by two motors [7] for 30 s whilst attempting to maintain steady postural control. The stimulus driving the sled was composed of 4 sine waves with different frequency content (0.18, 0.37, 0.69 and 0.9 Hz) and a velocity profile that ranged from 0 to 0.2 m/s (Fig. 1A). Subjects were blindfolded and wore earmuffs during the 30 s oscillation.

2.3. Objective and subjective measures of body sway

During the task, objective measures of body sway were collected using three sensors: a Fastrak electromagnetic (Vermont, USA) sensor placed on the C7 vertebra to record linear displacement of the upper body with respect to the platform [12,13]; a gyroscope placed on the right iliac crest recording the angular velocity of the hip movement and contact sensors placed on each foot sole to signal foot lifts off the platform (Fig. 1B). The subjective instability measure was collected immediately after the 30 s oscillation with a Likert scale that ranged from 0 to 10, with 0 being “completely steady” and 10 corresponding to “so unsteady I am about to fall” [7,8] (Fig. 1 C).

2.4. Priming paradigm

Visual priming: we randomly allocated participants into two groups. Both groups watched a video of an actor performing the same postural task that they subsequently performed (see 2.3). Participants randomly allocated to the “SteadyVideo” group watched a video of the actor performing the task with stability and participants assigned to the “UnsteadyVideo” group watched the same actor performing the task unsteadily (Fig. 1D). Both videos were identical in all other parameters apart from the actor’s postural performance.

Verbal priming: participants were given either erroneous information or no information regarding the amplitude of the upcoming motion stimuli (Fig. 1E). The sled oscillations were grouped in two conditions: “with”, or “without” prior information. In the “with information” condition, the information given to subjects classified the stimuli amplitude as either “Small”, “Medium” or “Large” but, critically, all trials had the same objective amplitude (maximum velocity of 0.1 m/s). In the “without information” condition, subjects were not given any verbal cues about the trial, but critically this time the sled movements did actually have either a “small amplitude” (peak velocity of 0.05 m/s), “medium amplitude” (peak velocity of 0.1 m/s) or “large amplitude” (peak velocity of 0.2 m/s) perturbation. All conditions and stimuli were randomly presented to subjects.

2.5. Questionnaires

In order to have a baseline measure of the subject’s anxiety, the Trait component of the State and Trait Anxiety Index was used (STAI) [14]. This questionnaire contains statements which assess an individual’s tendency to anxious characteristics (e.g. “I feel nervous and restless”). Subjects are asked to rate each sentence on a scale of 1–4 (with 1 = never, 2 = sometimes, 3 = very often, 4 = always).

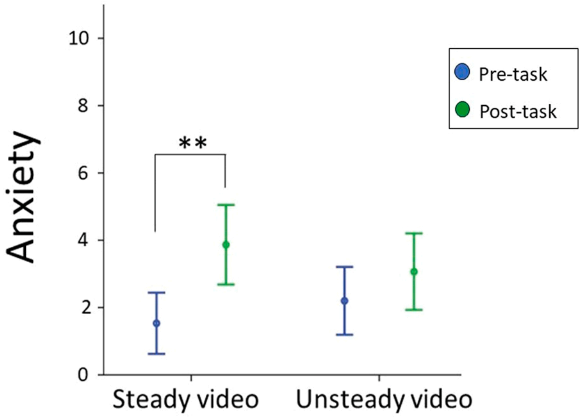

Fig. 2. State anxiety measures before and after performing the postural task for subjects who watched the Steady and Unsteady videos. Blue represents the pre-task measurement (but after watching the video) and green denotes the anxiety ratings after experiencing the task. Circles represent mean values and bars represent the error. A significant increase from pre to post task anxiety is observed only in the group that watched the Unsteady video ($p < 0.01$).(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.6. Experimental protocol

For the visual priming experiment, all participants initially completed the STAI questionnaire and subsequently watched one of the two videos of the task they would be completing (Either StableVideo or UnstableVideo). After watching the video, all subjects were asked about their anxiety towards the task with a Likert scale which ranged from 0 to 10 where 0 was “Not at all anxious” and 10 was “Extremely anxious/As anxious as I could be” (Fig. 1 C). This anxiety measure was aimed to identify the immediate effect of the video and it was used as a pre-task anxiety measure. Subjects then performed the postural task (with the same motion stimulus amplitude). After the postural task, their anxiety was measured again using the same Likert scale, corresponding to the post-task anxiety.

For the verbal priming experiment, after completing the STAI questionnaire participants were informed they were about to experience different magnitudes of sled oscillations and that prior information regarding the oscillation amplitude was going to be provided only for some of the trials. Subjects then performed the postural task with 3 different sled amplitudes- as depicted in Fig. 1E. Finally, after each trial the state anxiety measure was assessed using the same 0–10 Likert scale.

2.7. Statistical analysis

Statistical analysis was performed using SPSS version 24. Spearman correlations were used to investigate the relationship between variables, and regression model with curve estimation were used to analyse the objective-subjective instability relationship, as performed in previous studies [7,8]. To compare one measure between two independent groups, an independent t-test was used and for more than 2 groups, a one-way ANOVA was implemented. Finally, repeated measures ANOVA were used to compare paired data.

Considering the possible differences in postural control and emotional factors between males and females, we analysed the data and compared the results between both genders. No significant differences were observed between males and females on any of the analysed measures (objective and subjective). Accordingly, the analysis was performed using all subjects.

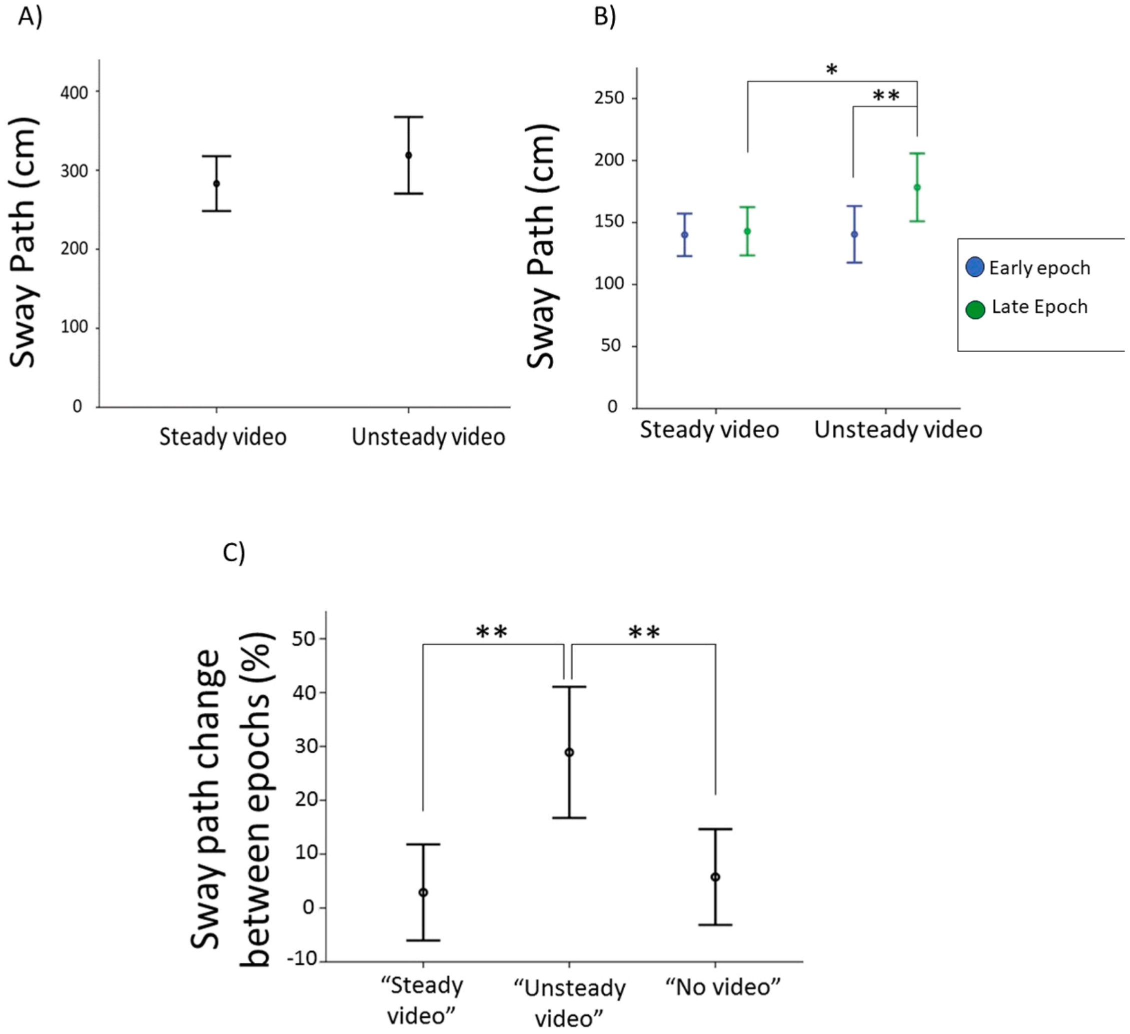

Fig. 3. A) Sway path (in cm) recorded during the postural task for subjects on the Steady video and the Unsteady video groups. B) Sway path for early and late epochs (15 s each) for both video groups. There is a significant increase in Sway Path from early to late epoch only in the group that watched the Unsteady video, making the late epoch on this group significantly different from the late epoch on the Steady video group. C) Sway path percentage change between forts and second epochs on the groups that watched the Steady and Unsteady videos and a third group of subjects who did not watched a video. A significant increase from early to late epochs was observed in the group watching the Unsteady video compared to the other two groups. Circles represent mean values and bars represent the error.

3. Results

3.1. *Visual priming experiment*

The subjective instability scores recorded after performing the task were similar for the SteadyVideo group compared to the UnsteadyVideo group (mean scores= 5.2 for SteadyVideo group and 4.7 for UnsteadyVideo group) (independent t-test,$p = 0.43$). With respect to state anxiety scores after watching the video (pre-task), no differences between the two groups either before ($p = 0.23$) or after task performance were found (t-test $p = 0.38$). However, we did observe a main effect of change in anxiety between pre and post task performance ANOVA ($F_{(1,28)}= 32.5$, $p < 0.001$), with the change being significantly larger for the SteadyVideo group ($F_{(1,28)}= 5.1$, $p < 0.05$, Fig. 2). Hence watching the steady video before task performance increased anxiety levels during the task. N.B. Objective measures of body sway (Sway path, hip velocity and foot-lift count) correlated strongly with each other ($p < 0.01$ for all correlations), as expected. Accordingly, for all further analysis we took sway path as a single representative parameter for consistency with previous studies [7].

There was no significant difference in sway path between both video groups (mean values= 283.02 cm for the SteadyVideo group and 318.83 cm for the UnsteadyVideo group, $p = 0.21$, Fig. 3A). However, as visual inspection of the data indicated a sway effect as a function of time, we separated the 30 s recordings into two epochs, of 15 s each (early and late). This revealed a significant difference between the early and late epochs, only for the UnsteadyVideo group; namely the sway increase during the last 15 s of the task compared to the first 15 s (repeated measures ANOVA, sway path change as main effect ($F_{(1,28)}= 16.93$, $p < 0.001$)). The SteadyVideo group showed similar sway values during both epochs (Fig. 3B). Hence, watching the unsteady video induced a late increase in sway during the task, as confirmed in the next paragraph.

In order to identify if the change in sway path between the two epochs was independent of priming, we analysed previous data (identical task, similar age) without visual or verbal priming [7]. A one-way ANOVA showed that the change observed in the UnsteadyVideo group was significantly different to that of the SteadyVideo group and indeed to subjects previously tested without any priming ($p < 0.01$, Fig. 3C). This indicates that the observed difference in sway between the first and second epoch is attributable to viewing the video with the unsteady performance. Critically, participants in the SteadyVideo group were matched for baseline demographics (age, sex) or trait anxiety scores (mean score= 40.33 for steady group and 40.27 for unsteady group) to

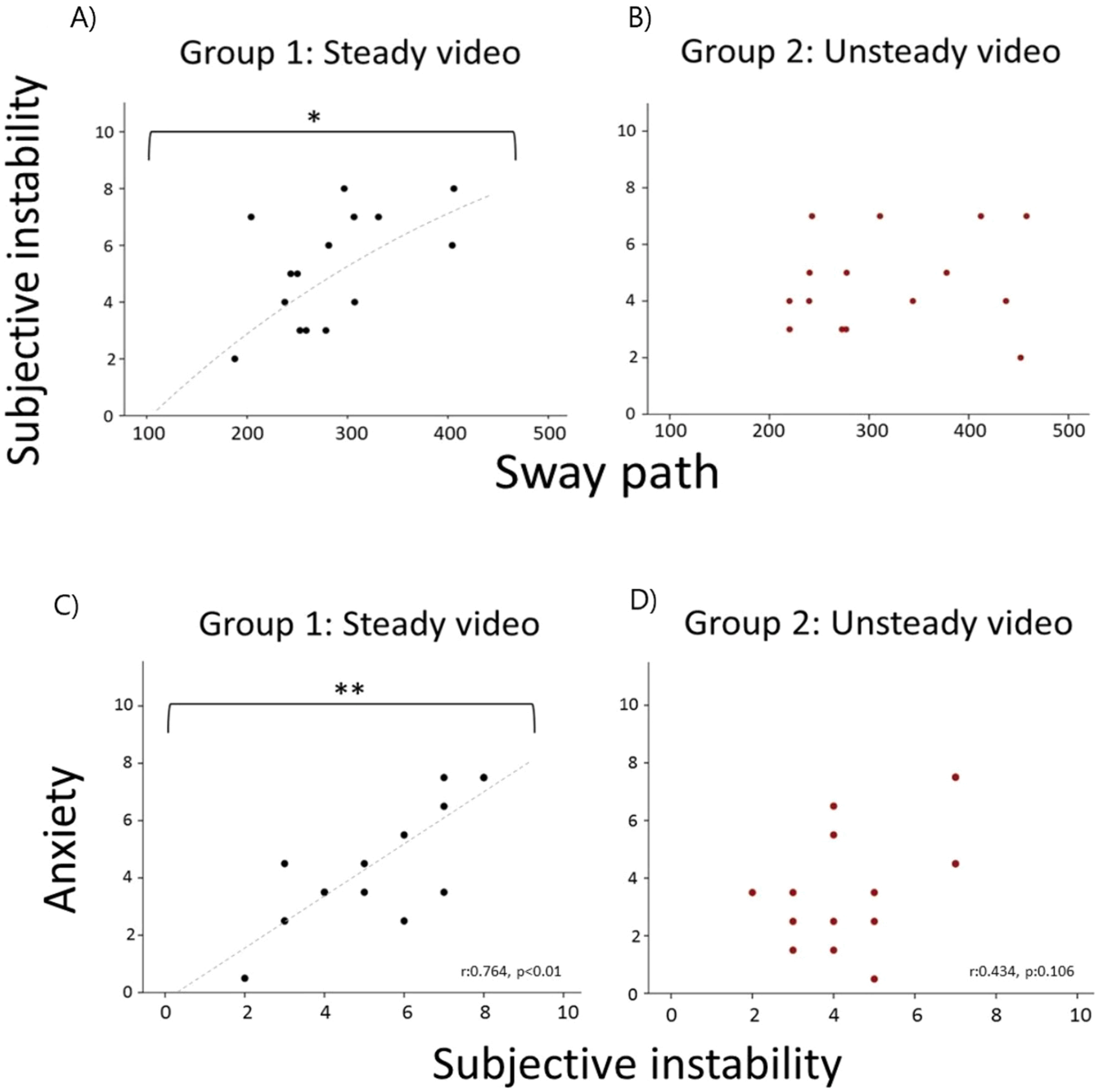

Fig. 4. Relationship between Sway Path (objective) and Subjective instability for both groups. A significant relationship was observed only in the group watching the Steady video (A), being absent in the Unsteady video group (B). The relationship between Subjective instability and Anxiety for both groups is displayed next. A significant relationship was observed only in the group watching the Steady video (C), being absent in the Unsteady video group (D).

participants in group UnsteadyVideo.

To investigate the relationship between objective and subjective measures of stability, which as aforementioned are typically coupled [7, 8], we correlated objective sway path measures with subjective instability scores in both video groups. The strong correlation normally present between objective and subjective instability measures was fully preserved in the SteadyVideo group (r:0.53, $p < 0.05$, Fig. 4A) but, critically, was absent in the UnsteadyVideo group (r:0.27, $p = 0.447$, Fig. 4B). Furthermore, as a strong relationship has also been observed between subjective instability and anxiety [7], we probed whether this association was disrupted by video viewing. We observed a strong positive correlation in the SteadyVideo group (r:0.767, $p < 0.01$, Fig. 4C), but there was no such relationship in the UnsteadyVideo group (r:0.434, $p = 0.106$, Fig. 4D). Hence, watching the unsteady video disrupted the normal relationship between subjective instability vs objective instability and anxiety.

3.2. Verbal priming experiment

In the “no information” trials, the sway path was significantly different between the three amplitudes as evidenced by a repeated measures ANOVA ($F_{(2,50)}= 226.565$, $p < 0.001$), hence confirming that the change in the stimuli amplitude was generating a change in body sway (Fig. 5A). In those individuals that received erroneous information about forthcoming sled movement (but actually exposed to the same sled velocity), they did not exhibit an increased sway path in relation to the magnitude of the priming (S:78.76 cm, M:80.55 cm and L:80.92 cm; repeated measures ANOVA, $p = 0.314$, Fig. 5B). Hence, giving no or erroneous information on the upcoming task did not affect objective postural sway.

Regarding the subjective measures, a repeated measures ANOVA demonstrated a significant increase in the perception of instability and anxiety with the change in sled amplitude ($F_{(2,50)}= 193.767$,$p < 0.001$ for instability and $F_{(2,50)}= 57.142$, $p < 0.001$ for anxiety, Fig. 6A) when no prior information was provided, in line with the observed change in sway path. Interestingly, in trials with erroneous prior information, perceived instability and anxiety across stimuli amplitudes was modulated by verbal priming despite no change in sway path ($F_{(2,50)}= 4.049$, $p < 0.05$ for instability; $F_{(2,50)}= 6.758$, $p < 0.01$ for anxiety, Fig. 6B). Hence, misleading information about the task influenced subjective but not objective sway parameters.

Regarding the relationship between objective and subjective

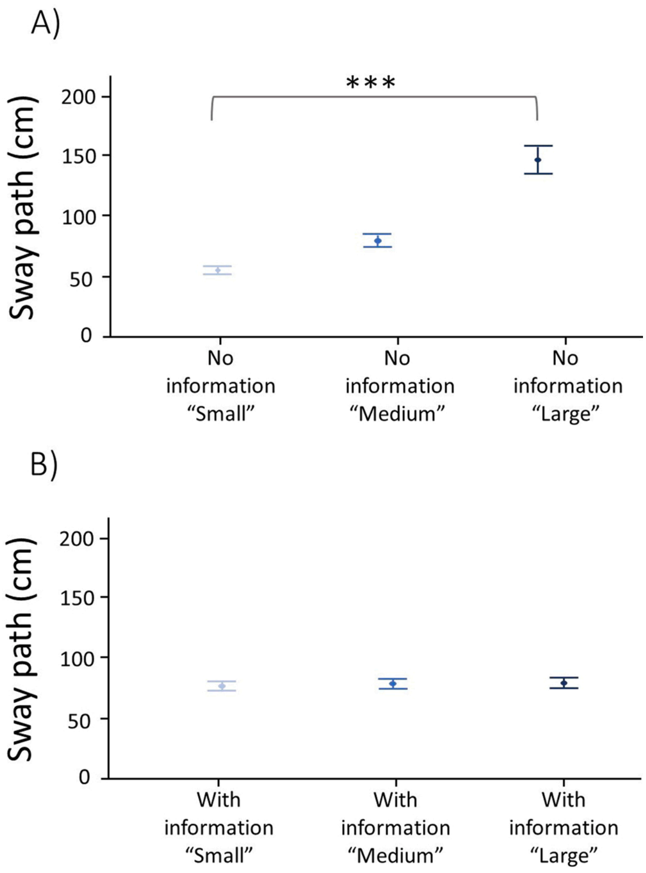

Fig. 5. A) Sway path (in cm) recording from subjects during the three sled amplitudes without previous information and sled velocity change. The increase in body sway across the amplitudes was significant ($p < 0.001$). B) Sway path (in cm) recordings from subjects when experiencing the three amplitudes with previous information but no real change in sled velocity. There is no significant difference in body sway on any of the amplitudes.

measures, a regression with curve estimation showed a logarithmic function during the 'no information' condition (r^2:0.574, $p < 0.05$), but an absence of any relationship when erroneous prior information was provided (r^2: 0.04, $p = 0.58$, appendix Fig. A1). Finally, there was a tight relationship between instability and anxiety for both conditions (r^2:0.707 for 'no information' and r^2:0.569 for trials where verbal information was provided).

4. Discussion

Here we sought to investigate whether modulating prior belief systems surrounding the difficulty of an upcoming postural task via the induction of expectational mismatch may distort the relationship between objective measures and subjective ratings of stability. We observed that erroneous visual and verbal priming disrupted the known relationship between the perception of stability and actual bodily displacement.

In the visual priming paradigm, body sway increased during the latter part of the task for subjects who had viewed the unsteady actor. Despite this increase in objective sway, their perception of instability was not significantly different from the group that viewed the steady video. Accordingly, the question that arises is why would an individual sway more but not report greater instability?

A possible explanation may be that the mismatch generated by the video primed the individual to expect a task that challenged postural control. Considering that responses to upcoming events is mediated by prior beliefs or assumptions [15], when participants came to actually perform the task, they found the task easier to perform in comparison to the priming-driven prediction regarding the difficulty of the upcoming task. Accordingly, such mismatch could have generated overconfidence and the adoption of a more relaxed strategy leading to increased sway but "no worries" about instability.

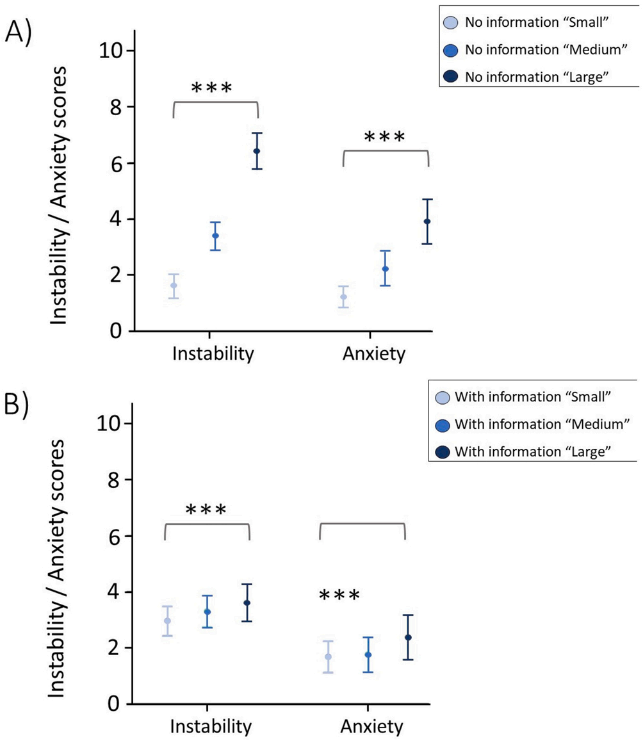

Fig. 6. A) Subjective instability and Anxiety scores provided by subjects during the three amplitudes without previous information but real sled velocity change. There was a significant increase in both Subjective instability and Anxiety across the three amplitudes. B) Subjective instability and Anxiety scores given by subjects during the three amplitudes with previous information provided but no objective sled velocity change. There was a significant increase in both Subjective instability and Anxiety across the three amplitudes.

Such a proposition is supported by previous work indicative that the motor cortex generates motor plans for expected experiences. These plans need to be modified accordingly when a mismatch between the expected experience and the physical experience occurs [16]. Applying this to our data, we postulate that during the initial part of the postural task subjects were bracing themselves for (i.e. expecting) a challenge that they predicted after viewing the actor in the unsteady video [17]. When this challenge never arose and subjects adopted a more relaxed postural strategy. This is consistent with the notion that the motor cortex can be activated with semantic incongruences related to movement, and that such activation can change the plan that the motor cortex has selected for the given task [16].

An alternative, albeit conceptually close and non-mutually exclusive explanation, is provided from the action-observation literature which suggests that cortical resources in such areas are shared with those involved in task execution [17]. Accordingly, then, it is expected that the visual priming in our subjects would have generated an equivalent change in the motor postural strategy in expectation of the forthcoming postural instability. Therefore, in our paradigm, when the real experience clashes with the expectation, this mismatch generates an opposite effect, i.e. subjects who expected a more destabilizing task experience less instability as compared to their actual performance, and vice-versa. Given the absence of any modulation in subjective ratings accompanying this objective change in body sway, we argue that either perceptual ratings are formulated early on during task performance or that such a change in postural strategy is not a fully conscious process.

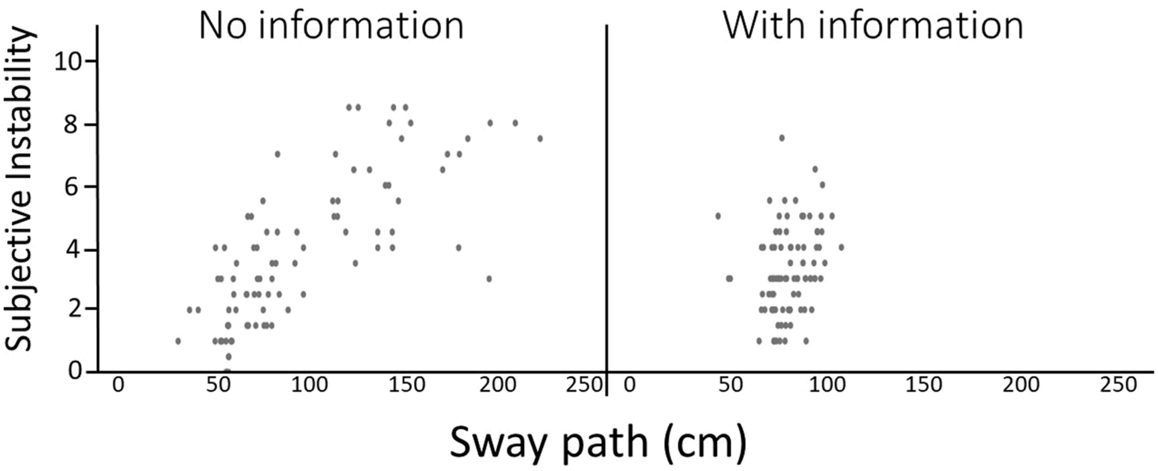

Fig. A1. Relationship between Objective (Sway path) and Subjective instability for both conditions. A significant logarithmic function was observed in the trials where no information, but sled velocity change occurred. This relationship was not observed significant in the trials with previous information but not platform velocity modification.

The decision to adopt the early/late epoch analysis is borne out of the idea that if you have primed an individual to receive expectational mismatch regarding the difficulty of an upcoming task – that will be at its greatest during the start of the trial (Early epoch). As the trial goes on (late epoch), the subject will have adapted to the expectational mismatch. Accordingly, adopting the early/late epoch analysis approach is important to understand how postural strategies change in accordance with online evaluation of expectational mismatch. Additionally, as seen with the anxiety analysis, the video did not generate significant differences in anxiety between groups in the pre-task measurement, but the mismatch did generate a significant change in anxiety in one group, supporting the idea of a possible change during the task, which we probed further.

In the verbal priming experiment, we observed that erroneous information about the amplitude of the forthcoming trials did not modulate the objective measures of body sway. However, it did distort the relationship between objective measures and subjective ratings of instability, mediated by the increased ratings of subjective perception of instability and task-related anxiety in the absence of any physical change in platform motion or associated body sway.

Critically, we observed this uncoupling between objective measures and perceptual ratings of stability only in participants that received both erroneous visual and verbal priming. These dissociations indicate that when priming modifies subjects' expectation it can alter not only objective motor performance, but also the subjective postural rating. Furthermore, given that both erroneous visual and verbal priming distorted the normal relationship between objective measures of body displacement, perceived instability and task-related anxiety during the postural task, one could argue that this such modulation is driven by emotional factors.

A possible mechanistic account for such influences can be derived from observations of a cortico-basal loop between areas of the limbic system and motor areas, implying that the limbic system provides an online threat assessment regarding body motion in space [18]. Surprisingly, limbic areas without any motor input were evidenced to generate motor output, hence showing how motor and their associated perceptual outputs can be modulated by: i) emotion and motivation [18], and ii) by threat and risk assessment [4,6,19–21]. Finally, the revealed connections between limbic and motor areas postulate that novel internal and external threats exert influence over motor output [18]. Considering that one of the main inputs used in the construction of perceived self-stability is the actual body movement, it is plausible that such a loop connecting emotion and motor control brain areas could modulate the normal relationship between objective and subjective measures of instability.

Regarding the directionality of the effect we report, the question remains whether increased anxiety increases instability or self-reporting heightened levels of instability, or, vice versa, experiencing increased instability leads to higher anxiety levels? Our data as illustrated in Fig. 2 shows that having watched the steady video induced anxiety during the task. This is presumably mediated by a combination of a fear of falling and/or startle, as the task is harder than predicted. This suggests that anxiety is not primarily driven by objective instability levels but by a central "risk assessment" process linked to arousal and ultimately involved in generating motor predictions [21]. Complementary findings came from the subjects who developed 'late' instability after viewing the unsteady video, likely via the 'over-confidence' mechanism described above. Thus, it seems that instability drives anxiety, rather than anxiety driving instability. Critically, the paradigm used in this study, is able to dissociate objective from subjective instability during a postural task, and in-turn identified that subjective instability is the reason for developing higher levels of anxiety.

For future studies, body mass index could be considered as a variable, to describe the specific influence it could have on the effect of priming or expectational mismatch on posture. Additionally, future work could also observe how anthropometric and psychological differences between males and females could affect postural control.

Taken together, our findings illustrate that modulating prior belief systems by inducing expectational mismatch via either visual or verbal priming can distort the relationship between objective measures and perceptual ratings of stability. The findings highlight the importance of prior expectation and anxiety upon the perception of self-stability. These findings may have clinical implications in balance disorder patients, particularly those with functional neurological disorders (i.e. Persistent Postural Perceptual Dizziness [22]) as well as those with functional gait disorders [23,24].

Funding

P.C. was funded by a CONICYT scholarship, Chilean government (Reference: 5235/2016).

CRediT authorship contribution statement

Patricia Castro: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Project administration. **Efstratia Papoutselou:** Formal analysis, Investigation, Data curation, Writing – original draft. **Sami**

Mahmoud: Formal analysis, Investigation, Data curation. **Shahvaiz Hussain:** Investigation, Data curation. **Constanza Fuentealba Bassaletti:** Investigation, Data curation. **Diego Kaski:** Writing – review & editing, Visualization. **Adolfo Bronstein:** Conceptualization, Methodology, Writing – review & editing. **Qadeer Arshad:** Conceptualization, Methodology, Writing – review & editing, Visualization, Supervision.

Declaration of interest

None.

Acknowledgments

This investigation was supported by the Imperial College London Biomedical Research Centre. David Buckwell provided technical support during the study.

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