Enhancing the Internal Representation of the Body Through Sensorimotor Training in Sports and Dance Improves Balance Control

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Abstract
Body internal representation (BIR) is built up from the integration of sensory signals and is essential to control movement and balance. Here we review different types of trainings involving sensorimotor experiences that improve the BIR accuracy, balance and movement production.

Keywords: Body internal representation; Balance control; Proprioception; Sensorimotor training

Abbreviations: APA: Anticipatory Postural Adjustment; BIR: Body Internal Representation; TPJ: Temporo-Parietal Junction

Introduction
Postural or balance control is of paramount importance for motor actions such as standing or walking. Interestingly preserving balance or body orientation while a voluntary movement is performed implies prediction of the postural disturbances provoked by the movement itself [1]. Indeed, limb or trunk movements induce a shift of body’s center of mass that can disturb balance if not compensated prior to their execution [2]. Such anticipated control of balance is grounded on the capacity of the brain to use a body internal representation (BIR) in space [3,4]. The BIR is built up and updated from multisensory integration involving proprioceptive, tactile, vestibular, visual inputs and is referred relative to a stable reference frame such as gravity. For example, the updating of the BIR through labyrinthine and muscle proprioceptive Ia inputs allows the fine tuning of the postural reactions following body disturbance [5]. It is worth noting that despite being important for calibrating proprioceptive inputs, visual information appears to be less involved than somatosensory for the fast updating of the body parts or whole-body position in space (i.e. BIR) required for enabling appropriate postural reactions. In this review, we will explore how the accuracy of the BIR can be improved by sensorimotor experience enabled by the practice of physical activities. We will particularly focus on activities that involve knowledge of the body parts’ relative motion and that require keeping or disrupting the vertical alignment of the body.

Discussion
Studies during the past three decades have demonstrated that dance or dance-like training improves the accuracy of the BIR [6-9] and changes balance control (i.e. anticipatory postural adjustments, APAs) associated with motor performance [10,11]. For example, Mouchnino et al. [11] showed that in dancers (over 15 years of modern dance practice and on-stage experience), the APAs prior to leg raising are highly accurate and do not necessitate online adjustments. The relative timing between the APAs and their movements of the leg also shows little variation. In non-trained participants, the APAs prior to leg raising are associated with greater online adjustments. This suggests that dance training allows developing an accurate internal representation of the body dynamics, which in turn enhances the use of an anticipated mode of movement control. While the “sculpting” of the BIR through high-level dance training is undisputed, some studies have shown that remodeling the BIR can occur within a few weeks of practice, even in participants with no regular physical activities. For example, creative dance programs using body communication through movements emphasizing body awareness (12 weeks with a periodicity of 3 sessions of 90 min per
two types of exteroceptors provide information about the body's movement. In judo, the sense of balance, primarily subserved by the vestibular system, is targeted by judo training. These exteroceptors are especially important for postural control and balance control. It is also clear that the sense of body position and movement, the sense of tension or limb stiffness, and the sense of balance (for a review, see [21]). It is also clear that the sense of balance as related to gravity and the location of the body center of mass with respect to the body surface in contact with the ground [2]. Together with exteroception, a major role of proprioception in the resetting of the BIR has been highlighted by showing that the representation of the limb in the motor cortex changes with body posture [22-24]. A shorter sensorimotor training focused on balance recovery from external perturbation could also change the quality of the BIR as evidenced by a change in balance control [25]. These authors showed that balance stability is improved by stimulating proprioceptive afferences during a short training period (4 weeks, 4 times a week) consisting in different exercises on an unstable support (i.e. wobbling boards, spinning tops and different kinds of soft mats and cushions). In addition, modification of APAs which rely on the use and the quality of internal representation of the body position in space [26] can occur after similar short training. This is observed in patients with chronic pain who’s APAs are known to be delayed [27,28]. For instance, Hwang et al. [28] showed that the APAs prior to arm flexion occur earlier in patients who followed an intervention program based on exercises performed in a quadrupedal stance or in a supine position on a wobble board (i.e. an unstable disk perched on half a ball) (40-min sessions, five times a week during 4 weeks) than in patients who subscribed to classic physical therapies over the same period of time. Surprisingly, highly trained athletes also benefit from short specific proprioceptive training. This has been shown in Olympic windsurfers that used either a dry-land proprioceptive training (3 times a week for 6 weeks) or a fitness training, in addition to their outdoors training [29]. Both athletes of both groups were highly trained and skilled in maintaining their equilibrium on an unstable support, only those who have benefited from the proprioceptive training significantly improved their balance control. The increased ability to rapidly trigger adapted postural responses to external perturbations is consistent with an enhancement of the BIR after a training focused on proprioceptive information processing (e.g., judo, wobble board).

Conclusion
To conclude, this mini review showed that either long-term training or short periods of practice might improve the accuracy of the BIR in space. Such training, based on sensorimotor tasks that highly involved body sensation, could be relevant for motor rehabilitation after injuries or in patients suffering from balance impairments (e.g. parkinsonians or obese patients).

Conflict of Interest
None of the authors have potential conflicts of interest to be disclosed.

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