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Which mechanisms underlie sensorimotor adaptations to perturbation-based balance training?

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ABBREVIATIONS
PBT perturbation-based balance training

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Unpredictable large-magnitude perturbations frequently cause a loss of balance. Tripping and stumbling, for example, are estimated to be the second major cause of falls in long-term care facilities for older adults.[1] In laboratory settings, rapid and unexpected forces applied to the hip/trunk or disruptions to the support base have been used to simulate a loss of balance in real life. Under such conditions, individuals perform one of the many possible arm and leg movements to compensate for the loss of balance and recover a controlled posture or gait. The compensatory movements tend to scale with perturbation magnitude, as small perturbations evoke reduced amplitude or even motionless responses and large perturbations can elicit wide arm movements and single or multiple steps for restoring balance.[2]

A related point of theoretical and translational interest that has attracted considerable attention for improving the resistance to falls is the use of perturbation-based balance training (PBT). In a seminal study, Horak et al.[3] examined how postural responses adapt to 100 sudden backward translations of the support base. The authors found that participants recovered equilibrium faster during the last compared with the initial perturbations, and that these adaptations were accompanied by reductions in leg muscle activation and ankle torques. Subsequent studies on PBT have targeted age-related impairments in compensatory stepping and grasping balance recovery reactions using unanticipated serial displacements of the support base while standing, and lateral support base translations, trips, or slips when walking. PBT reduced the frequency of unstable compensatory multi-step reactions and foot collisions in response to mediolateral perturbations. Provoking trips or slips while walking has also led to improved balance recovery, marked by more effective compensatory responses,[5] and retention of the improved responses over time.[6] The translational relevance of PTB has been evidenced from reduction of both slip-induced fall rates[7] and fall-related injuries,[8] as assessed with a prospective daily fall diary, in community-dwelling older adults. Together, the data suggest that when exposed to repeated unanticipated balance perturbations, individuals retain and generalize improved compensatory movements to restore balance in response to perturbations occurring in contexts different from that experienced during training. In other words, PBT seems to induce learning effects.

The notion that compensatory arm and leg movements are learnable like a voluntary motor skill was recently explored by testing the motor learning principle of contextual interference in PBT.[9] Effects of random and blocked perturbation schedules were compared for retention and generalization of stability gains of compensatory movements. Random schedule training led to retention and generalization for more challenging perturbations of higher platform velocity and performing a cognitive task while responding to perturbations. The block schedule training, conversely, led to poor retention and generalization effects, achieving equivalent results to those of untrained individuals. These findings showing the benefit of random over blocked schedule of serial perturbations support the perspective that PBT leads to learning of generalizable compensatory movements to recover balance following unpredictable perturbations, allowing one to deal with perturbations distinct from those experienced during training. Neurophysiological support for the notion that PBT induces learning effects was provided by evidence that serial slip-like perturbations led to improved balance recovery in ensuing slips in parallel with a changed pattern of activation of different cortical areas including the dorsolateral prefrontal and superior parietal cortices in slipping imagery.[10] This finding of a changed pattern of cortical activation following serial slips substantiates the notion of learning-related functional modifications in higher order control structures as a result of adaptation to balance perturbations.

A debatable issue, however, is the mechanism underlying improvement of resilience promoted by PBT against postural perturbations. While this topic has been left virtually untouched thus far, potential explanations for the benefit of exposure to unpredictable balance perturbations can be conceptualized as follows:

1. At the functional level, systematic exposure to diverse balance perturbations may lead to development of an improved capacity to use online sensory feedback, signaling the direction and magnitude of body imbalance to appropriately select and scale arm and leg reactive movements leading to balance recovery.

2. At the neural level, based on evidence for increased activation of the prefrontal and parietal cortices following training based on repeated slip-like perturbations during walking,[10] PBT can be thought to promote strengthened connectivity between those cortical areas, leading to fast selection and scaling of appropriate compensatory movements to deal with the requirements posed by a particular balance perturbation.

While appealing, it is expected that future studies reveal which mechanisms underlie sensorimotor adaptations to PBT. By understanding the mechanisms of how resistance against balance perturbations is developed, we could improve the procedures employed in PBT with particular benefit for individuals with an increased risk of falls.

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