Two ways to save a newly learned walking pattern

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Savings, or faster relearning after initial learning, demonstrates humans' remarkable ability to retain learned movements amidst changing environments. The ability to save what is learned over time is particularly important within the context of walking, as gait rehabilitation specialists aim to build upon what has been learned previously with each repeated therapy session. However, the mechanisms underlying savings remain controversial [1,2]. Here, we used a split-belt treadmill to study precisely how people save newly-learned walking patterns. We hypothesized that simply learning a new walking pattern is not enough for savings, but rather the learning environment influences the ability to save.

In Experiment 1, we investigated savings by systematically varying the learning and unlearning environments. We first compared savings after participants gradually (Gradual) or abruptly (Abrupt) learned a 2:1 split-belt walking pattern over a ten-minute adaptation period (Exp 1 protocols and results shown in Figure 1). We observed savings in the Abrupt group ($p<0.001$) but not the Gradual group. We then studied why these groups differed. First, we tested whether the number of context switches mattered: the Abrupt group experienced three abrupt contextual switches while the Gradual group experienced only two. We tested a Gradual Washout group to remove one abrupt context switch and still saw savings identical to the Abrupt group. Second, we tested whether the amount of time at the full 2:1 perturbation mattered—the Abrupt group experienced the full split for ten minutes while the Gradual group experienced the full 2:1 split for only 30 seconds. We studied an Extended Gradual group to match the time at full perturbation and saw partial savings. Third, we tested whether a Short Abrupt group that had only a brief experience of the full abrupt perturbation could show savings. Here we found partial savings, similar to the Extended Gradual group. Thus, we conclude that savings is driven by at least 2 factors: previous exposure to similar abrupt changes in the environment and by the amount of exposure to the new environment. As relearning was strikingly fast in the Abrupt group, we then asked whether humans store explicit information about the learning environment that can be readily recalled upon future exposure to the same environment, despite the fact that locomotor control is generally thought to be largely automatic.

In Experiment 2, we investigated whether people can explicitly recall previously-experienced walking environments and whether this was affected by the same factors that influenced savings in Experiment 1. Similar to Experiment 1, participants learned a novel split-belt walking pattern and then underwent a washout period. Following washout, participants were asked to try to reproduce the split belt perturbation using a hand held controller (Exp 2 protocols and results shown in Figure 2). We first studied Abrupt and Gradual groups similar to those in Experiment 1. The Abrupt group re-created the learning environment with greater accuracy than the Gradual group ($p=0.01$); interestingly, all participants in the Gradual group selected a right belt speed that was slower than the actual speed experienced during learning. We then studied an Extended Gradual group, finding that these participants performed similarly to the Gradual group ($p=0.19$) and were marginally less accurate than the Abrupt group ($p=0.06$). These findings indicated that abrupt changes in the environment lead to more accurate knowledge of either the environment or the learned walking pattern. Subsequently, we investigated whether participants recalled the environment or the specific learned walking pattern. The Opposite Abrupt group was identical to the Abrupt group, except that they adapted with the left leg moving twice as fast as the right and then were asked to make treadmill move as it had during the initial learning period but with the belts switched. We hypothesized that the Opposite Abrupt group should perform similarly to the Abrupt group if they recalled explicit information about the environment but markedly worse if they attempted to recall the walking pattern, since they had not previously experienced the walking pattern they were asked to reproduce. Here, we found that the Opposite Abrupt group performed similarly to the Abrupt group ($p=0.48$), indicating that the participants recall the environment irrespective of the walking pattern.

In summary, we found that savings of a learned walking pattern depends on two factors: previous exposure to similar abrupt changes in the environment and the amount of exposure to the new environment. Interestingly, learning in response to abrupt changes (vs. gradual changes) in the environment leads to greater explicit knowledge of the learning environment, even after the learned pattern has been washed out. This suggests that humans store explicit information about the environment in which a new walking pattern is learned and use this information to facilitate faster recall of learned movement patterns upon subsequent exposure to previously-experienced environments. Supported by NIH R01 HD048741.

References [1] Huang VS, Haith A, Mazzoni P, Krakauer JW. 2011. Rethinking motor learning and savings in adaptation paradigms: model-free memory for successful actions combines with internal models. Neuron 70(4):787-801. [2] Smith MA, Ghazizadeh A, Shadmehr R. 2006. Interacting adaptive processes with different timescales underlie short-term motor learning. PLoS Biol 4(6):e179.

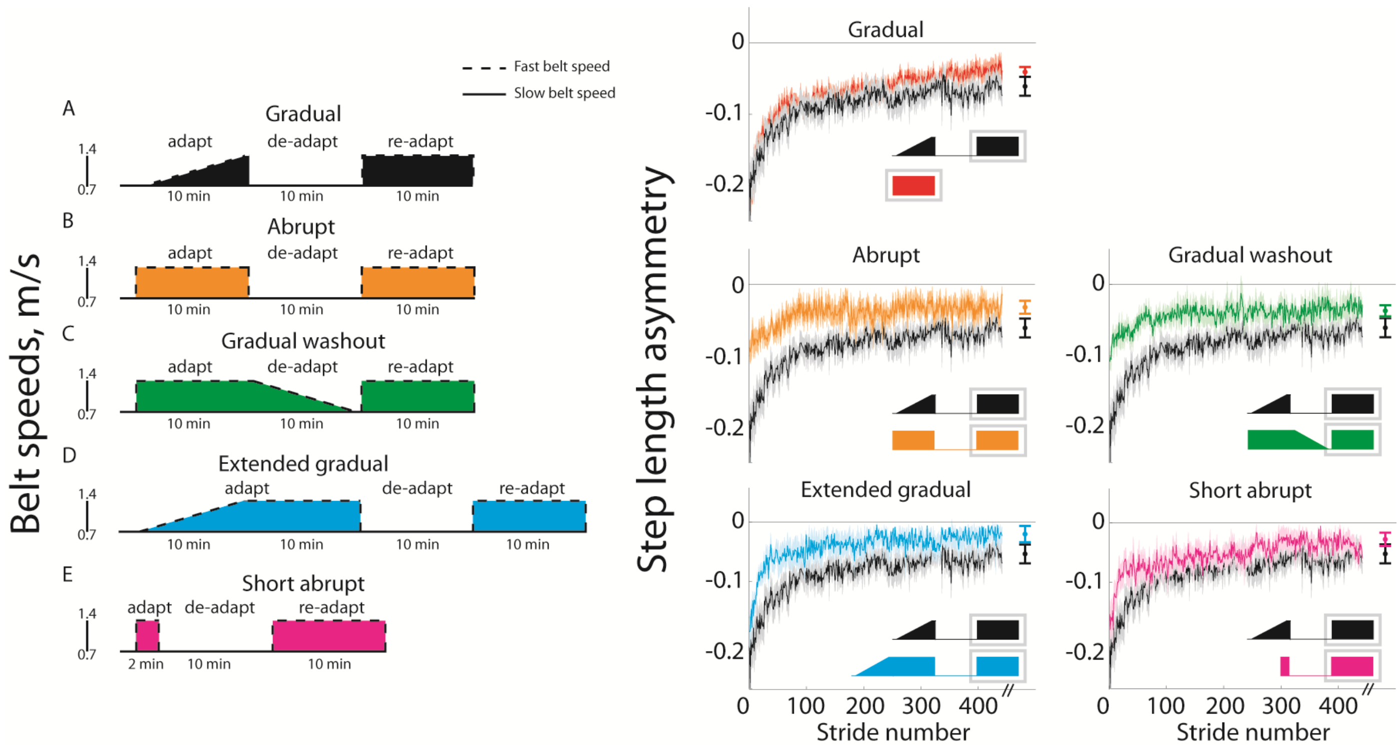

Figure 1. Left: Protocol diagrams are shown for A) Abrupt, B) Gradual, C) Gradual Washout, D) Extended Gradual, and E) Short Abrupt. Dashed and solid lines indicate the speeds of the fast and slow belts, respectively, when the belts were split. If only a solid line is shown (as during Baseline), both belts moved at the same speed.

Right: Comparison of step length asymmetry during re-adaptation among the groups that showed no savings (top: Gradual - black), most savings (middle: Abrupt – orange, Gradual Washout – green), and intermediated savings (bottom: Extended Gradual - blue, Short Abrupt - pink). Shown are mean curves across participants within each group (all n=12) ± standard error. Data points immediately following each Adaptation 2 curve show the step length asymmetry during plateau (mean of the last 30 strides) for each group (mean ± standard error). Gray outlines behind the protocol diagrams included on the top right of each set of curves outline the portion of the protocol from which the data is presented.

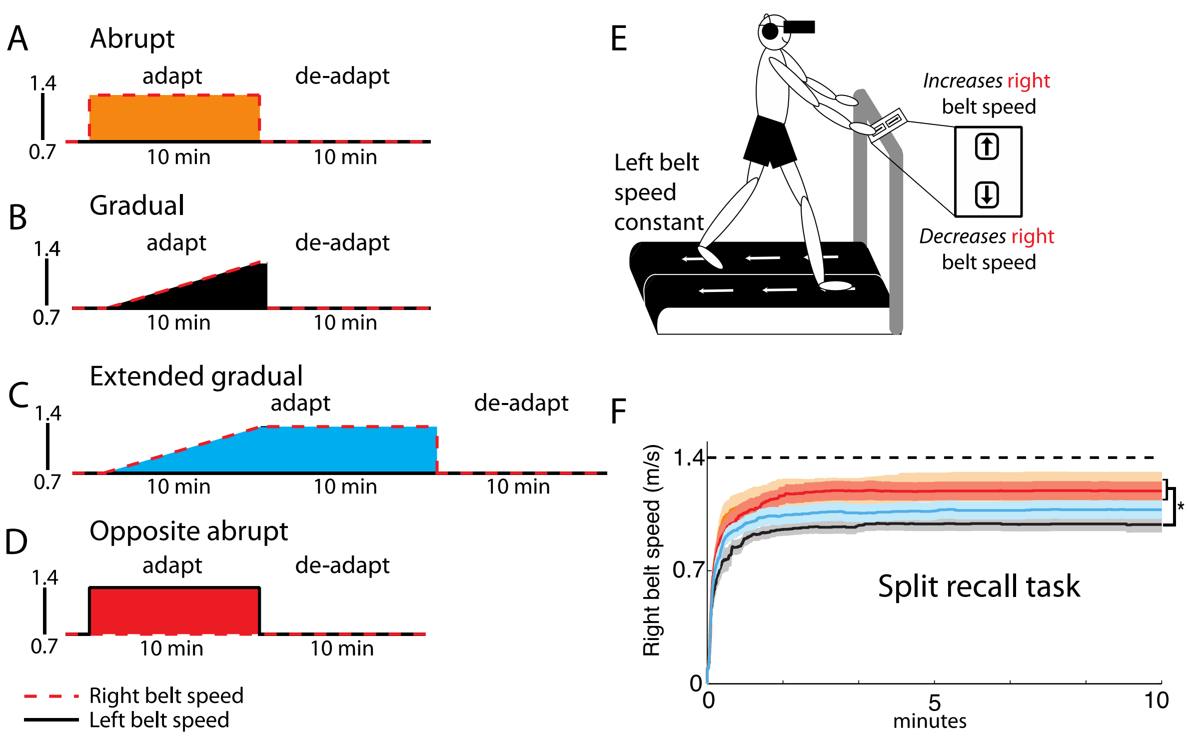

Figure 2. A) Protocol diagrams are shown for A) Abrupt, B) Gradual, C) Extended Gradual, and D) Opposite Abrupt. Dashed and solid lines indicate the speeds of the right and left belts, respectively. Immediately following de-adaptation, all participants performed the split recall task. E) Diagram for split recall task experimental setup. F) Comparison of the right belt speeds selected during the split recall task among groups. The Abrupt (orange) and Opposite Abrupt (red) groups selected significantly faster speeds and were closer to the target speed of 1.4 m/s when compared to the Gradual (black) and Extended Gradual (blue) groups. *indicates $p<0.05$.