One step backwards, two steps ahead: Amplifying movement errors to improve walking post-stroke

Treatments to rehabilitate walking following nervous system damage tend to focus on correcting or minimizing movement errors. For instance, treadmill training – a well-studied and widely-used form of locomotor therapy – is often accompanied by assistance from a therapist, or sometimes a robot, to guide leg movement towards an “ideal” trajectory (reviewed in Dietz, 2009; Harkema et al., 2012; Hesse, 2008; Hesse et al., 2001; Hubli and Dietz, 2013; Mauritz, 2002). For optimal outcomes, it may be important to introduce some variability in the path of the guided movement (Edgerton and Roy, 2009; Ziegler et al., 2010). Nonetheless, these types of treatments emphasize the correction of abnormal gait kinematics and kinetics. Treadmill training has been shown to improve aspects of functional mobility, including postural control, gait speed, and endurance. However, other aspects of walking, like spatiotemporal gait symmetry, may be more resistant to change (Hornby et al., 2008; Patterson et al., 2008; Silver et al., 2000).

In recent years, another approach to gait rehabilitation has emerged: rather than correcting movement errors, this approach focuses on augmenting errors. This is accomplished by taking advantage of the nervous system’s ability to adapt. Here, adaptation is defined as the process of gradually modifying a well-practiced movement to accommodate a novel, perturbing context or environment (Martin et al., 1996). Introducing a perturbation that exaggerates movement errors initially makes the movement worse. Over time, however, errors are reduced to baseline levels as the nervous system makes adjustments to the feedforward motor plan. These adjustments persist when the perturbation is removed, resulting in “aftereffects” that correct the original errors. People with cerebellar damage are impaired in adaptation tasks, suggesting that the cerebellum plays a critical role in recalibrating feedforward motor plans in response to sensory feedback (Maschke et al., 2004; Morton and Bastian, 2006; Smith and Shadmehr, 2005). In contrast, people with cerebral damage due to stroke are capable of adapting and storing aftereffects (Reisman et al., 2007), which presents the exciting possibility of using adaptive techniques to improve movement errors in this population.

Indeed, the potential for using adaptation as a tool to improve walking post-stroke and in other neurological populations is currently being explored by several groups. One approach uses a split-belt treadmill, which has two belts that can drive each leg at different speeds, to exaggerate step length asymmetry in people with hemiparetic gait due to stroke (reviewed in Bastian, 2008; Reisman et al., 2010; Torres-Oviedo et al., 2011; Vasudevan et al., 2010). Aftereffects following adaptation to split-belts can restore gait symmetry and allow these individuals to take equal-sized steps (Reisman et al., 2007, 2009). Another approach uses a robotic gait orthosis (Lokomat) to apply velocity-dependent resistance against hip joint movement in people with motor-incomplete spinal cord injury (Houldin et al., 2011; Lam et al., 2008). A short period of practice with resistance results in aftereffects that temporally increase step length and hip flexion angle during swing phase (Houldin et al., 2011; Lam et al., 2008). One promising aspect of gait adaptation training, regardless of whether a split-belt treadmill or a robotic orthosis is used, is that a very short period of practice (<10 min) can result in large changes in gait kinematics. However, there are also some limitations. For instance, these devices may, at present, be prohibitively expensive for some rehabilitation clinics. There is also limited research on the longevity of aftereffects following adaptation, particularly in patient populations.

The expense of some adaptation devices is not an insurmountable problem. There is a growing body of work investigating simpler and less expensive methods to apply a mechanical perturbation during gait by, for example, adding resistance to the movement of one leg using a weight or elastic (Blanchette and Bouyer, 2009; Fortin et al., 2009; Lam et al., 2009; Noble and Prentice, 2006; Regnaux et al., 2008). In this issue of Clinical Neurophysiology, Savin and colleagues used such a device to perturb swing phase (Savin et al., 2014). A rope was attached to the participant’s ankle, the other end of which was passed through a set of pulleys and attached to a weight equivalent to 1.25% of the participant’s body weight. The pulleys redirected the force applied by the weight such that forward movement of the leg was resisted. Previously, this group has shown that adaptation to this swing phase perturbation can temporally change step length symmetry in non-disabled individuals and in people with stroke (Savin et al., 2010, 2013b). The current paper extends this result by showing that these aftereffects generalize to walking over the ground, resulting in improved gait symmetry for people with stroke in natural walking conditions.

Savin et al. (2014) take this finding one step further by also quantifying the rate of decay of over ground aftereffects. Interestingly, they found over ground aftereffects decayed at a slower rate in stroke participants compared to controls. This is despite the fact that there were no differences between groups in the adaptation rate or in the decay rate of aftereffects on the treadmill. This suggests that stroke impairs the ability to make quick modifications...
to gait when the context changes from, for example, treadmill to overground walking. This also indicates that people with stroke will get several steps (approximately 12 steps, on average, versus six steps in controls) to practice a more symmetric gait pattern over ground before these aftereffects dissipate and walking returns to the baseline pattern.

Are the results of this study meaningful to rehabilitation? First, it is worth considering whether a more symmetric gait benefits functional mobility in people with hemiparesis. Step length asymmetries have been associated with decreased propulsive force of the hemiparetic limb and decreased work and power of the hemiparetic plantar flexors (Balasubramanian et al., 2007; Bowden et al., 2006). Furthermore, a couple of long-term gait training studies have shown improvements in step length symmetry that occur in parallel with improvements in perceived effort of walking (Reisman et al., 2013) and increasing gait speed (Hall et al., 2012) in individuals with stroke. On the other hand, other studies have reported that functional mobility gains with locomotor training are not correlated with changes in step length symmetry (Hornby et al., 2008; Patterson et al., 2008). In the present study, Savin et al. (2014) showed that over ground gait speed in stroke participants was reduced in early post-adaptation, when gait was symmetric, compared to baseline and late post-adaptation, when gait was asymmetric. That is, gait speed was reduced when the asymmetry was corrected. It is premature to infer too much from this result, since symmetric gait was probably unfamiliar and not well-practiced in these individuals – increasing speed when returning to asymmetry may simply reflect returning to the comfortable pattern. It remains to be seen whether increased practice with symmetric gait over time will result in faster walking speed or other improvements in functional mobility.

A second point to consider when evaluating the relevance of this task to gait rehabilitation is whether long-term retention is possible. Reisman et al. (2013) showed that four weeks of adaptation training on a split-belt treadmill could lead to improvements in step length symmetry that are retained for upwards of three months in people with stroke. This demonstrates that short-term adaptation may be a precursor to longer-term forms of learning. The true strength in using adaptation in the context of rehabilitation, however, may be its ability to produce rapid and large changes in movement. Perhaps an optimal approach would be to augment errors early in a treatment session to drive the nervous system to adapt and correct these errors. Following this, clients could be encouraged to continue using the corrected pattern for a period of time via more traditional rehabilitation methods, like treadmill training with therapist assistance. In fact, Reisman et al. (2013) took such an approach: at the end of each split-belt training session, participants practiced walking over ground with a therapist providing verbal feedback to reinforce step length symmetry. At this time, it is not clear whether practice with reinforcement of the corrected movement is a critical ingredient for retention of locomotor adaptation. Regardless, it is apparent that there is potential for using adaptive strategies to achieve long-term changes in gait kinematics post-stroke.

In summary, Savin and colleagues have shown that a short period of walking practice using a simple, inexpensive device that resists swing phase movement can temporarily improve over ground walking symmetry in people with stroke and hemiparesis. They also demonstrated that stroke participants continued using the altered gait pattern longer than controls. This is quite promising for rehabilitation, since it suggests that one could intervene during this extended window of altered gait symmetry to reinforce the pattern with additional practice and/or feedback provided by a therapist or computer (e.g., Hussain et al., 2013). Altogether, this work clearly advances the development of rehabilitation strategies that take advantage of the nervous system’s ability to adapt.

Smith MA, Shadmehr R. Intact ability to learn internal models of arm dynamics in Huntington’s disease but not cerebellar degeneration. J Neurophysiol 2005;93:2809–21.

