The Split-Belt Walking Paradigm

Exploring Motor Learning and Spatiotemporal Asymmetry Poststroke

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KEYWORDS

• Stroke • Motor learning • Locomotion • Split-belt • Adaptation

KEY POINTS

- The split-belt paradigm can be used to examine motor learning or potentially as a rehabilitation intervention after stroke.
- After stroke, patients retain the ability to adapt their walking pattern to new constraints.
- Locomotor adaptation and learning may be slowed after stroke.
- Exaggeration of spatial gait asymmetries using the split-belt treadmill results in improved spatial gait symmetry.

INTRODUCTION

Stroke is the leading cause of long-term disability in the United States, with approximately 795,000 people experiencing a new or recurrent stroke each year.[1] A primary concern of individuals experiencing a stroke is the ability to regain ambulatory function.[2] Moreover, improved ambulatory function after stroke is linked to increased community participation, improved cardiovascular fitness, and decreased risk of stroke recurrence.[1] As such, gait retraining is a major component of rehabilitation.[3]

Gait after stroke is characterized by pronounced asymmetry.[4] Following stroke, individuals increase reliance on the nonparetic lower extremity in static standing as well as during ambulation. This results in a shortened nonparetic swing phase and

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increased stance phase on the nonparetic lower extremity. The resulting spatiotemporal asymmetries (stance time, swing time, and step length asymmetries) are well documented in individuals after stroke.[4,5] Step length asymmetry, in particular, has been shown to influence other gait deviations. By taking a shorter nonparetic step, the propulsive force of the paretic limb is decreased, thereby limiting forward propulsion of the body.[6] Step length asymmetry and its associated gait deviations have been linked to decreased walking speed[6,7] and efficiency,[8] as well as decreased dynamic balance,[9] thereby limiting safe functional ambulation. Various novel rehabilitation interventions have attempted to target these asymmetries to improve safe locomotion. In particular, several studies have utilized principles of motor learning to target specific gait deviations utilizing a split-belt treadmill.[10–13]

The split-belt treadmill has 2 independent belts, one under each leg, so that subjects can walk with belts moving at the same speed, tied, or with the belts moving at different speeds, split-belt. By splitting the treadmill belt speeds in a 2 to 1 ratio, the paradigm requires both neurologically intact subjects[14] and subjects after stroke[10] to alter their coordination while walking. Initially, both spatial and temporal characteristics of step symmetry are altered; however, over a period of 10 to 15 minutes, this asymmetry will be reduced with the use of trial-and-error practice.[10,11,14] When returning the treadmill to a normal walking condition or a tied-belt configuration, both neurologically intact subjects and poststroke subjects demonstrate after effects, with a reversal of the initial asymmetry induced by the split-belt treadmill configuration. The presence of this after effect indicates that the nervous system has learned and stored a new locomotor pattern.[10,14,15] The use of trial-and-error practice, or adaptation, to a perturbing environment provides important insight into the ability of the poststroke central nervous system (CNS) to temporarily store and recall a motor memory.

Thus, the split-belt treadmill paradigm allows exploration of various aspects of motor learning, including adaptation and retention of a novel locomotor pattern, but also allows exploration of the capacity of the nervous system for error recognition and correction. Recent evidence suggests exaggeration of poststroke gait asymmetry using the split-belt treadmill can lead to after effects, resulting in a more symmetric pattern of walking on the treadmill as well as over ground.[10,11] With repeated exposure to split-belt treadmill walking subjects after stroke demonstrate longer-term improvements in step length symmetry.[12,16] Consequently, the split-belt treadmill can be utilized to facilitate improvements in asymmetric gait after stroke, or can be utilized as a specific probe of motor learning. This article discusses the current role of the split-belt treadmill in the examination of locomotor learning as well as a potential therapeutic tool for intervention in individuals after stroke.

ADAPTATION

Research employing principles of motor learning, specifically adaptation, have recently gained interest because of the ability to target specific gait abnormalities in individuals after stroke.[10–12,17] Within these studies, adaptation may be defined as the process of modifying or adjusting an already well-learned movement or motor skill based on error feedback.[15] This process of adaptation occurs over a period of trial-and-error practice in response to novel task demands.[15,18] Given this definition, motor adaptation can be considered as 1 specific component of motor skill learning. Once fully adapted, storage of a new motor pattern within the CNS is reflected through after effects. Upon removal of the stimulus, the subject is not able to retrieve the previous motor behavior.[19,20] The subject must de-adapt, during a period of continued practice without the perturbation, in order to return to his or her previous baseline motor performance.[20,21]