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Retraining Automaticity: Recovering the Procedural Memory of Walking after Stroke

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Abstract

Walking upright, on two feet, without a cane or other assistive device - is perhaps the most ubiquitous and arguably the most human of all procedural memories. Yet, walking did not start out as a procedural memory that we were innately born able to do. How did walking become “automatic”, or procedural? Is that capacity lost after stroke? The motor control for walking, while it can be adjusted for environment and task, is a relatively individualized pattern superimposed on many basic similarities from person to person. The pathway by which we develop “our” recognizable pattern of walking includes two essential ingredients. First, we need an environment that allows for locomotion as a primary means of transit (i.e., repetitions). Second, we need sufficient demand (in the form of dual task distractions) to push the organization of the motor control of gait into the more primitive structures of the basal ganglia and cerebellum. Our recognizable “walk”, evolves over time and, barring injury or change in somatotype (e.g., significant weight gain or loss), remains relatively constant through our adult years. In this paper, we will discuss both what is known in regard to creating this procedural memory, and what is known about re-creating this level of automaticity, particularly after stroke.

Keywords: Automaticity; Stroke; Gait

Introduction

Approximately 450,000 people survive their first stroke each year in the United States [1,2]. A majority of cerebrovascular accidents (CVA) or strokes lead to limitations in the ability to walk, as stroke is a leading cause of disability in the United States [1]. Clearly, a stroke in the main motor centers of the cortex and internal capsule will directly impair walking. As walking is a complex task, strokes that affect vision, sensation, coordination, without direct lesion to the motor centers in the cortex or the cerebellum, will additionally result in observable gait impairments, be it expressed in safety or independence. Additionally, lacunar strokes affecting subcortical structures of the basal ganglia and thalamus affect gait, through the operating systems and interconnected nature of gait transitions and adaptability – turning, slowing, accelerating, adjusting to environmental demands (e.g., friction or uneven surfaces). Our main means of functional mobility, ambulation or “gait” is nearly inescapably affected somehow, after a stroke, as more than half of stroke survivors over 65 years old experience reduced mobility.[1] Because of the many means by which even one category of diagnosis – stroke – can affect gait, the potential and methods for recovery are quite diverse. However, the goal for all stroke rehabilitation would remain the same: restore patient’s automatic gait function, so it can be carried out reliably without increased cognitive burden.

Relearning to walk after sustaining a stroke may involve compensation, using a new area of the brain to substitute for the lesioned areas (e.g. primary motor cortex and conscious control of each step in gait), and early recovery strategies (assistive device, preferential weight shift, bracing) after stroke do encourage this behavioral adaptation [3-5]. While this functional recovery, toward meaningful and in some cases independent gait is occurring, the system may be charged to undergo a corollary process of neuroplasticity. Already well-cited and detailed elsewhere, neuroplasticity includes making and growing new connections as well as reorganization of responsibilities. Neuroplasticity is a viable option in most every stroke survivor and may not have the burden of a timeframe since stroke to be a viable option for improvement [3-5]. Partially because of the distributed responsibilities and complexities of gait, it is challenging for a person to truly make a complete recovery of ambulation after a stroke. Even when a person returns to an assemblance of normal in observation of gait, have they truly regained the act of walking in the same manner that they had prior to the event? One of the reasons that this is challenging to answer is because the act of walking is a procedural memory, stored in a normal central and peripheral nervous system. The task remains flexible and responsive to environmental demands (adaptability), yet can be operated largely without conscious control of the frontal lobe in steady-state and predictable environments. Can a person regain the procedural memory of walking after a stroke? If so, how? If the recovery is incomplete, is striving for the development of a new procedural memory with consideration for current capabilities (hemiplegia, sensory impairments, abnormal tone) still desirable? What are the mechanisms by which we can facilitate a return of the old procedural memory, or the creation of a new, reliable program that, albeit changed, can also operate without conscious control?

What is a Procedural Memory?

Memory is not a single entity or process, we have multiple memory systems [6] that can work independently or in concert with each other [7]. It is widely accepted that we have both a declarative and non-declarative memory systems. The declarative memory system allows

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us to recall, think about and discuss (or declare) our recollections. The non-declarative memory system includes procedural memory, which supports motor behaviors. The declarative system relies on medial temporal brain structure, such as the hippocampus [8], while procedural memory relies more on frontal-striatal systems [7]. The split between declarative memory and procedural memory was made clear with a patient known as H.M. After part of his medial temporal lobes were removed, H.M. couldn't make new declarative memories but he could make new procedural memories, indicating an anatomical and functional dissociation between these memory systems [9]. Procedural memories are important for many of our daily activities, we use procedural memories to help us walk, sit, stand, use eating utensils, drink from a cup, use a phone, type, and brush teeth. Therapists often work on these tasks, in order to maximize independence and quality of life. If someone has severe amnesia, like we would see in the later stages of most types of dementia, repeats a motor behavior many times, in the same sequence, without error, then they can develop a new procedural memory [10]. The ability to create new procedural memories in the absence of declarative memories is an important intervention tool for therapists.

Another feature of procedural memories is their automaticity. Orrel and colleagues [11] reported that people who had experienced strokes could learn to do a balancing task, even if they lacked explicit or declarative knowledge of that task [11]. In other words they learned how to do the task but they lacked any knowledge of the task that they could think or talk about. Similar effects are possible for walking among people who have experienced a stroke. Kal and colleagues conducted a meta-analysis looking at the effects of procedural learning in people who experienced strokes [12]. The authors concluded that there is good theoretical support for the hypothesis that procedural learning can lead to improvements after a stroke, they asserted that there is a need for additional empirical evidence in this area. It is at this very point that we propose a seminal shift in the approach toward regaining automaticity. In their discussion, Kal and colleagues noted limitations in the studies that were included in the meta-analysis. We are adding to this list of limitations and proposing practical methodological change that can be implemented in the clinic and laboratory alike, described below.

Gait Features, Storage Centers, Neural Control

Every person's walking is uniquely "theirs" due to anthropometrics, personality, fitness, nurture (observation and imitation of those around them in development), and impairments (arthritis, restriction after chronic ankle sprains, etc). The commonality that we all share is more so in where we store walking and the motor programming therein, rather than the result of what "it" looks like, the effects of the motor program [13].

The act of walking has a general "set" and organization of efferent neural control that has diverse location in the primary motor area (M1), the supplementary motor area (M2), the Basal Ganglia, and the cerebellum as "procedural memory centers" [13]. Reinforcing this concept are recent studies including Lee and colleagues' 2017 study that cites the loss the procedural pattern of gait in subjects with caudate lesions [14]. Procedural memory centers have output through the internal capsule, brainstem, spinal cord, and peripheral nervous system. Most certainly, the parietal lobe and cerebellum share sensory responsibilities to monitor the map and expectations of the act of walking, while the cerebellum receives a copy of the intended act – and serves as an online or real-time comparator. We will not belabor the sensory system's map of walking here, but rather refer the reader to Takakusaki's (2017) [14] review for a more detailed explanation.

The importance of neural control centers for walking, in this paper, becomes how. How did walking come to be stored in these locations? Are we born with the organization of walking as an a priori procedural memory with the motor control established? If we have "centers of gait control" or a central program generator – are we born with this…or is it developed? While neural centers are "in place" for a maturation of walking and mobility, the transition to get to walking most often goes through the developmental stages, including activities that only gradually begin to approximate walking. Arguably, the act of walking itself, once achieved at +/-12 months, has benefited along the way from rolling, creeping, crawling, and plantigrade stages more so from the resources (muscular strength and endurance in the core and extremities), than from a central neural standpoint (motor program of walking). So, if the procedural memory of walking has not truly been created/formed until we walk – how, then, does walking become a procedural memory? Just like any other procedural memory, walking takes repetitions in isolation and repetitions with dual task demands, to become a well-formed, resilient procedural memory.

Developing Automaticity: Repetitions and Dual Tasking

As an adult, with 6-10,000 steps per day, gait should be well-formed as a procedural memory [15-17] given – as long as they are free of other influences (e.g., clothing or footwear changes, pain, etc). Clearly, the more skilled a person is, the harder it is to distract them enough to affect their performance [15-20]. Examples include the elderly patient that is not acclimated to new footwear, is ambulating with a new assistive device, is experiencing ankle pain, or is 5 days post surgical from total knee replacement. These individuals are not operating under full automaticity and can be more easily affected with distractions.

In a related consideration, patients with mild cognitive impairment (MCI) may have fewer cognitive resources to devote to the "equation" of dual task tolerance [21,22]. In contrast, redundancy or reserve in intelligence and cognition can afford enough shared resources to divide (simultaneous), or decide (allocate appropriate resources through filtering) when faced with dual task demands.

How many repetitions of a task are needed, to make it "automatic", though? What are the testable parameters to define "arrived" for automaticity [23,24]? It is difficult to estimate the number of trials needed to make a new procedural memory, as many factors are likely to influence the outcome. The timing of the rehearsal trials matters, for example, we know that spaced retrieval can lead to new skill development much quicker than other rehearsal schedules, even for people with cognitive impairment [25,26]. Another factor is whether the learner can use declarative memory to support the development of the new procedural learning [21]. If the learner needs to inhibit an existing procedural memory, in order to perform a new behavior that could also reduce the efficiency of learning.

Popularized in the 1990s, body-weight supported treadmill training (BWSTT) provided a stimulus for the research and clinical practice of gait rehabilitation after stroke. This environment of care provides safety, graded weight-bearing, avenues for task-specific overtraining, higher intensity, and reduced demand on therapists to afford more repetitions and more mobilization of the moderately and severely impaired patients [27-29]. The rehabilitation of gait after stroke continues to evolve through technology, including feedback platforms, body-worn sensors, virtual reality, and by many other means [30-32]. Through all of these advances in technology and evidence, a consistent element of retraining gait, is repetitions. As noted above and additionally supported in normal motor control acquisition, repetitions are one necessary element that must be included as humans build procedural memories and gain automaticity. Can automaticity be acquired by repetitions alone, or does the normal, much less impaired nervous system need a “push”, a stimulus that requires the motor act be processed without conscious control? Here lies the essential question behind the novel application of dual task training that we are suggesting, provided *not merely to reduce fall risk in distracting environments*, but for the identified purpose of improving the very task from which we lure attention from. This is accomplished by a very familiar strategy in rehabilitation that is perhaps not so apparent under the veil of dual task training - that strategy being forced use. Dual task training forces the mechanics of gait to be processed and eventually stored at a procedural level, a stimulus that can lead to more reliable, immutable, and permanent motor control - resistant to interactions with the environment and affording a more adaptable survivor.

While dual-task demands are everywhere, no two people should be affected by the same environmental and task demands in the same manner. This variability is due to: 1) their past experiences with the proposed task or related tasks; 2) their relative automaticity in a primary motor task (influencing the cognitive reserve available); and 3) each person’s tolerance for a specific type of secondary task. Everyone has an individual skill set with both biological and experiential (nature and nurture) influence. As will be discussed later in this paper, research has clearly identified that gait can be altered through distractions. This is quantifiable. Dual task cost, the measure of dual task tolerance as noted earlier, has been shown to be higher with age, certain disease states, and with given levels of experience [33-37]. Variables from person-person in DT cost or tolerance is thought likely due to resources of conduction speed and reaction time, among other variables.

While there is general consensus that divided attention negatively impacts our ability to make new declarative memories [38]. However, it is less clear whether and how divided attention affects the development of procedural memories and their automaticity. Dividing attention might affect features of procedural memories and motor learning by impairing declarative memories that might support effective behavioral expressions [38]. For example, one might be learning to use a (4 legged) “quad” cane, which would be motor learning, but the use and initial practice with the quad cane might be supported by the declarative memory that the cane should be placed in the opposite hand, from the injured or weak leg. Performance will suffer without that declarative knowledge. But other researchers have found that divided attention might aid certain aspects of motor learning. Divided attention has been shown to help learning for a visual - motor task relative to undivided attention or no training at all [39]. But it could be that for easier tasks the greater attention given under divided attention or dual task conditions could lead to better performance [40,41].

Methodologies of Testing Distraction Influence on Gait

Rehabilitation professionals continue to recognize but not yet fill the void that we have in both understanding and testing the effects of attention, and more specifically distractions, on mobility. Quite simply, we cannot reliably measure dual task tolerance in a valid and sensitive manner without contrived test batteries – yet. While there is often recognition of dual task intolerance, we do not have evidence-basis behind our practice to measure, prognosticate a response or justify further care.

There is increasing evidence to support the disabling effects of distractions on gait in people that have sustained a stroke. There is disagreement in exact methodologies for how to study this effect. Additionally, the predictive value across dual task testing to fall risk, remains elusive. Most typically, studies do operationalize the primary task as ambulation. The variables combined with walking have a broad range, and have included: 1) various types of secondary task distracter, or “modes” of distraction: cognitive, visual, auditory, or manual [42,43]; 2) different methodologies (testing each task as a single-task prior to combining) [43,44-47]; 3) considerations of task complexity/novelty and reality (meaning how contrived or reality-based the task should or can be) [42,47], and 4) different forms of walking (direction, or speed) including backwards, self-selected, and maximal efforts [42,47]. In all, the most common investigations in dual task literature are dual task cost (DTC) or dual task effect (DTE), being the statistical reflection of change in performance in the primary task from single-task to dual task conditions. In many recent studies, scientists have measured cost for walking and the distracter, in an attempt to investigate the relative cognitive participation for each stimulus [42,44-47]. Well-established tests that are intended to reflect DT capacity include versions of the Timed Up and Go test, specifically the cognitive and manual dual task versions (CTUG and TUG-m). Each version retains the physical TUG test and was developed by the original TUG author, Shumway-Cook and colleagues [48-50]. Respectively, these versions superimpose serial subtraction and holding a cup of water, while conducting the timed walk test. Each test has inherent limitations in that the secondary tasks are not measured for accuracy or participation and, arguably (using McIsaac’s definition [21]), may not truly be a secondary task, but rather just a more complex version of the TUG.

Yang and colleagues (2016) [51] studied three different modes of dual task interference for chronic stroke survivors (verbal fluency, serial 3 subtractions or carrying a cup of water), across four different conditions of walking (walking forward at self-selected and maximal speed, walking backward at self-selected speed, and crossing over obstacles). In each condition, the participants’ performances in gait, as well as their cognitive participation/accuracy, were measured. The authors found a strong correlation with the cognitive version of the Timed Up and Go (CTUG) [51]. This study provides insight and contributes to the literature with some novel considerations in regard to the gait parameters for dual task testing.

Emerging DT testing strategies include overlaying distractions during sensory-organization testing (SOT), clinical test of sensory integration in balance (CTSIB), and timed [44,46,52] or sensor-based measurements during an ADL or in gait. Still, the most common applications of DT testing in the clinic include the CTUG and TUG-M, or an application that includes an overlay of common psychological tests such as the Auditory Stroop or Trails B tests [53-54] in function. The future of dual tasking is likely to soon include more wireless gait analysis, as this is presently being explored on a clinical basis.

As noted above, a more recent consideration of dual task testing and examination includes the recognition of the types of distractions, or dual task modalities. These distinct modalities include: cognitive, visual, auditory, and manual distractions [42,43]. Table 1 describes the four modalities and provides some examples of each in daily function.

Rehabilitation of Dual Task in Gait…or Rehabilitation of Gait…in Dual Task?

As yet, our science for rehabilitative "loading" and expectations to improve DT tolerance *and* automaticity in gait, is imperfect and developing [55]. Here is where the science of neuroplasticity and motor learning – including intensity and task specificity more than any other concepts – have been incompletely applied in most of the research on dual task *training* to date. Studies on testing for the presence of dual task cost, for the relative increase in fall risk, for the effects of age, and for various task combinations – are not at fault. The limitations have been in training. Research that has been designed to investigate retention of motor learning through dual task training – essentially toward a dual task development of a procedural memory or to show greater automaticity after training [55], has largely been poorly designed. Methods in these studies have included sufficient numbers of repetitions, yet have not applied sufficient intensity. The principle of frequency, intensity, type and time (FITT principle) [56], as well as those principles cited of neuroplasticity and motor learning [57,58], lead us to the understanding that it is not the sheer numbers of repetitions or minutes-spent in dual task training, but the level of rigor, complexity, challenge and ultimately intensity – that has the opportunity to make each repetition meaningful and sufficient to induce measurable change. The FITT principle, outlining all of the ingredients: frequency, intensity, type and time sheds light on the shortcomings of research to date – delivered with no standard of intensity or citation of error rate that the subjects experience. Recent studies in stroke rehabilitation bear this out in comparing higher-intensity training to longer, more moderated-intensity deliveries as well [57]. Recall that dual task training, delivered at a rigorous level, is supported to induce neuroplasticity by the seminal article on such, Kleim and Jones' 2008 writing – directly in the complexity and intensity realms [58]. Gait training with dual task overlay is complex, by application, but only intense when applied so relative to the learner or subject's capabilities and readiness [58].

As for the application of dual task training, therapists must conduct their efforts in motor learning for the primary task of gait, with a consideration for both individualizing and later integrating dual task overlay. This must be carried out using reasonable expectations based on lesion size and location, age, learning style, and personality [59-69]. As McIsaac and colleagues [21] wrote, "*In aging and disease states, declines in sensorimotor and cognitive functions may lead to reduced postural reserve and cognitive reserve creating overall greater demands for attention to the task.*"

While all dual-tasking must be proportionate to capabilities, success rates, and personal tolerance (see previous section), we must recognize additional trends by diagnosis and age. Therapists must watch for signs of DT overload, including agitation, pathway deviation, foot clearance, steps to turn, dramatic reductions in gait velocity, poor sequencing of assistive device, and increased losses of balance requiring assistance. As stroke is not a heterogeneous condition, clinicians should *not* assume that all groups have a timetable upon which they are "ready" for dual task interference to be introduced. Additionally, not all stroke survivors necessarily possess the capacity to overcome their DT intolerance. For example, some stroke survivors with right hemisphere dysfunction (syndrome of neglect and hemianopsia after stroke known as RHD) and contraversive lateropulsion tendencies may not tolerate distractions at all, given their lesion-induced loss of awareness and perceptual impairment. Similarly, some patients with lacunar infarcts in the basal ganglia and cerebellum may have lost too much capacity in key procedural memory centers to reasonably improve in automaticity through this approach. Finally, those patients sustaining a stroke in the key attention centers such as the DLPFC or subservient dopaminergic pathways to the frontal lobe may be intolerant or unable to improve with this approach [70-72].

Wang et al (2015) [73] performed a meta-analysis of studies including cognitive motor interference (CMI) as part of their intervention for gait rehabilitation in stroke. The authors reviewed 15 studies in their paper, covering nearly 400 subjects. Those subjects in CMI groups experienced a greater gain in gait speed (as measured by the following tests: 2-min walk, 6-min walk, 10-m walk, 400-m walk), stride length, cadence, and balance (static, forceplate measurements + Berg Balance Scale), than their cohort controls. Changes in step length, Timed Up and Go, as well as center of pressure sway distance were all insignificant, between the two groups. Additional carryover was seen in Activities of Daily Living (ADLs) using the Functional Independence Measure (FIM) [73].

In a 2014 study by An and colleagues [74], stroke participants were assigned to three different dual task groups in a unique paradigm. Subjects were trained with motor (manual) dual task challenges (tossing up and catching a ball, re-hanging loops on different hooks, and buttoning/unbuttoning; holding a cup of water, or receiving/pouring water from a cup); or dual task cognitive (discerning colors, mathematical subtraction, verbal analogical reasoning, spelling words backward, and counting in reverse); or a combination of these (receiving both stimuli in a matching total dosage to the other groups). The authors found each group to have improved across outcome measures of gait speed, balance, and agility, while the cognitive + motor group was found to have greater gains in each outcome measure.

Clinical applications of DT training are only as sophisticated as the evidence to date. As it is functionally relevant to focus on

Table 1: The modalities of dual task distractions with functionally-relevant task examples.

Mode of distraction or secondary task	Functional example ***combined in gait***
Cognitive	Mentally rehearsing a shopping list Attending to a conversation with facts (phone number, date)
Auditory	Listening intently to a conversation or radio program
Visual	Searching for lost keys in a room Walking down bleacher stairs, watching an event
Manual	Feeling for keys in a purse Texting Pouring a liquid from a bottle to a glass

ambulation, the task specific nature of DT practice in the clinic often stops there. Asking patients to perform mathematical calculations spell words backwards, or name state capitals are cognitive tasks that many clinicians have applied, but are they functionally relevant? While these paradigms can be effective in *testing* DT, they likely fall-short of task specificity and should not be expected to translate from training to *function*. As we mature in DT applications, clinicians can be seen incorporating cell phones; pulling items from a purse, wallet, or pocket; recalling information delivered prior-to and after a primary task (requiring cognitive rehearsal during); utilizing obstacles for visual distraction; and overlaying relevant auditory distractions during the motor task. In all, the best DT training takes into consideration the following:

1) Patient's relative experience or level of automaticity with the primary gait task. Is the patient using a new assistive device? New footwear? Will distractions interfere with motor learning [14,21,23]?

2) Transfer of training (what are and how can training imitate the environmental demands for this person? [42,43])

3) Lesion location/type (what strengths and limitations are superimposed neurologically by the stroke?) [74].

4) Patient tolerance of error - consider personality. Will this person improve or become more frustrated by the DT loading [43]?

5) Specificity. Exposure to one condition/environment of gait or modality of DT condition should not be expected to transfer to skill (tolerance) in another [42].

6) Intensity. For dual task experiences to induce change and stimulate procedural processing of a primary task, they must be of sufficient challenge to offer a therapeutic dosage [42,76].

7) Awareness. The ultimate indicator for DT prognosis in recovery. Does this person:

a. Recognize dual task conflict. Are they able to perceive and independently recognize reduction in primary performance?

b. Recognize as they are being distracted?

c. Independently re-prioritize attention for their own safety, attempting to extinguish or filter-out distractions.

It is through these 7 considerations, that we can both guide our dual task intervention and individualize care, providing each person the greatest opportunity to recover. Prior studies, such as those cited by Wang (2015) [73], may have a wide-range of outcomes, due to the variability in application of dual task training, across one or more of these variables. The most likely dosage-based limitation of prior studies is the application of intensity. As Merzenich [77] and Kleim [78] suggested at III STEP, neuroplasticity is driven by challenge – "The task must also be difficult enough to introduce a threat of failure in order to maintain focused attention on the task." Patients should be provided the opportunity to experience some measure of failure, such as allowing them to lose their balance (but not fall), take protracted amounts of time for bed mobility, hit their wheelchair against walls, or attempt to propel themselves in a wheelchair with the brakes locked. It has been argued that the most effective way to help a patient's awareness evolve is to allow a problem to occur in a safe, meaningful and relevant environment [77-80].

For stroke survivors, the evidence is irrefutable and conclusive, dual task gait training can and often is beneficial for when adhering to principles of task specificity and intensity at the least. Many authors have postulated the mechanism by which this is true, with the most common theme being one of motor learning, specifically engaging the learner to re-automatize the primary task of walking, by organizing the effort of gait on external feedback. In other words, gait training by itself may be beneficial, yet this approach allows the learner to internalize the focus of attention on the movement itself. Dual task training forces an external focus of attention, which has proven to be a superior form of training for stroke and many other impaired and un-impaired (athletics, developmental learning, etc) conditions [75,81,82].

Recommendations for Future Research

Throughout the history of neurologic rehabilitation, a primary goal in recovering walking after stroke has been to regain symmetry. Symmetry, it has been thought, meant more gait efficiency and lower fall risk, as well as increased speed and lower levels of walking disability. Gait symmetry after stroke is indeed a noble goal, and should remain a goal. However, ultimately walking disability, the actual amount of home and community based walking activity, is likely more important to people with stroke. Although there are many factors that likely influence walking activity post stroke such as gait speed, functional balance, self-efficacy, and motor function; walking endurance as measured by the 6MWT appears to be the strongest predictor [83,84]. This begs the question, "Is it possible that through increased dual task training, and subsequent "forced" creation of a procedure of walking (motor plan considering the new post-stroke capabilities of the system), that a stroke survivor would have lower gait variability and therefore higher performance throughout the length of this standardized test? Would lower gait variability translate to improved confidence to re-engage in the world? Clinical experience bears this out. Theories support this notion. The laboratory awaits.

Summary

Evidence suggests that stroke survivors can make new procedural memories. The extent to which these memories are identical to pre-stroke patterns of gait, or are well-reinforced and novel iterations of post-stroke gait, is based on the type of stroke, the location of the stroke, access to rehabilitation, comorbidities, social support, personal traits, and many more factors, as suggested by the International Classification of Function [85]. Creating dual task interference during gait training has the proven capacity to take the recovery of gait from a conscious-control frontal lobe process and make it subcortical again. Limitations of this line of research to date can be found in the lack of respect for principles of task specificity and intensity. Additionally, most dual task research has been designed to prove the presence of dual task cost, or its relationship to fall risk, rather than the potential benefits in applications in rehabilitating the automaticity of gait. As noted above, it is time to mature from the notion of rehabilitating dual task tolerance in the activity of gait, to the more sophisticated and functionally-relevant notion of rehabilitating gait, through the application of dual task interference.

References

1. Benjamin EJ, Blaha MJ, Chiuve SE, et al. on behalf of the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics—2017 update: a report from the American Heart Association. Circulation. 2017; 135: e229-e445. CITATION 2 J Am Heart Assoc. 2016 Nov 14; 5(11). pii: e004282.
2. Medford-Davis LN, Fonarow GC, Bhatt DL, et al. Impact of Insurance Status on Outcomes and Use of Rehabilitation Services in Acute Ischemic Stroke: Findings From Get With The Guidelines-Stroke. J Am Heart Assoc. 2016; 5. pii: e004282.
3. Caleo M. Rehabilitation and plasticity following stroke: Insights from rodent models. Neuroscience. 2015; 311: 180-194.
4. Jones TA. Motor compensation and its effects on neural reorganization after stroke. Nat Rev Neurosci. 2017; 18: 267-280.
5. Levin MF, Kleim JA, Wolf SL. What do motor "recovery" and "compensation" mean in patients following stroke? Neurorehabil Neural Repair. 2009; 23: 313-319.
6. Squire L. Memory systems of the brain: A brief history and current perspective. Neurobiology Of Learning And Memory [serial online]. 2004; 82: 171-177.
7. Roy S, Park N. Effects of dividing attention on memory for declarative and procedural aspects of tool use. Memory & amp; Cognition [serial online]. 2016; 44: 727-739.
8. Moscovitch M, Nadel L, Winocur G, Gilboa A, Rosenbaum R. The cognitive neuroscience of remote episodic, semantic and spatial memory. Current Opinion In Neurobiology [serial online]. 2006; 16: 179-190.
9. Scoville W, Milner B. Loss of recent memory after bilateral hippocampal lesions. Journal Of Neurology, Neurosurgery & amp; Psychiatry [serial online]. 1957; 20: 11-21.
10. Middleton E, Schwartz M. Errorless learning in cognitive rehabilitation: A critical review. Neuropsychological Rehabilitation [serial online]. 2012; 22: 138-168.
11. Orrell A, Eves F, Masters R. Motor learning of a dynamic balancing task after stroke: implicit implications for stroke rehabilitation. Physical Therapy [serial online]. 2006; 86: 369-380.
12. Kal E, Winters M, Scherder E, et al. Is Implicit Motor Learning Preserved after Stroke? A Systematic Review with Meta-Analysis. Plos One [serial online]. 2016; 11: e0166376.
13. Lee KB, Kim JS, Hong BY,etal. Clinical recovery from stroke lesions and related outcomes. J Clin Neurosci. 2017; 37: 79-82.
14. Takakusaki K. Functional Neuroanatomy for Posture and Gait Control. Journal Of Movement Disorders [serial online]. 2017; 10: 1-17.
15. Killeen T, Easthope CS, Demkó L, et al. Minnimum toe clearance: probing the neural control of locomotion. Sci Rep. 2017; 7: 1922.
16. Ashby FG, Crossley MJ. Automaticity and multiple memory systems. Wiley Interdiscip Rev Cogn Sci. 2012; 3: 363-376.
17. Ericsson KA. Expertise and individual differences: the search for the structure and acquisition of experts' superior performance. Wiley Interdiscip Rev Cogn Sci. 2017; 8.
18. Clark DJ. Automaticity of walking: functional significance, mechanisms, measurement and rehabilitation strategies. Frontiers in Human Neuroscience. 2015; 9: 246.
19. Galit Yogev G, Hausdorff JM, Giladi N. The Role of Executive Function and Attention in Gait. Mov Disord. 2008; 23: 329–472.
20. Springer S, Giladi N, Peretz C, Yogev G, Simon ES, Hausdorff JM. Dual-tasking effects on gait variability: the role of aging, falls, and executive function. Mov Disord. 2006; 21: 950–957.
21. McIsaac T, Lamberg E, Muratori L. Building a Framework for a Dual Task Taxonomy. BioMed Research International. 2015.
22. Brown SW1, Collier SA, Night JC. Timing and executive resources: dual-task interference patterns between temporal production and shifting, updating, and inhibition tasks. J Exp Psychol Hum Percept Perform. 2013; 39: 947-963.
23. Wayne PM, Hausdorff JM, Lough M, et al. Tai Chi Training may Reduce Dual Task Gait Variability, a Potential Mediator of Fall Risk, in Healthy Older Adults: Cross-Sectional and Randomized Trial Studies. Frontiers in Human Neuroscience. 2015; 9: 332.
24. Sarkar M1, Fletcher D. Psychological resilience in sport performers: a review of stressors and protective factors. J Sports Sci. 2014; 32: 1419-1434.
25. Hsu C, Lin L, Wu S. The effects of spaced retrieval training in improving hyperphagia of people living with dementia in residential settings. Journal Of Clinical Nursing [serial online]. 2017; 26: 3224-3231.
26. Zmily A, Mowafi Y, Mashal E. Study of the usability of spaced retrieval exercise using mobile devices for Alzheimer's disease rehabilitation. JMIR Mhealth And Uhealth [serial online]. 2014; 2: e31.
27. Wonsetler EC, Bowden MG. A systematic review of mechanisms of gait speed change post-stroke. Part 1: spatiotemporal parameters and asymmetry ratios. Top Stroke Rehabil. 2017; 24: 435-446.
28. Srivastava A1, Taly AB, Gupta A, Kumar S, Murali T. Bodyweight-supported treadmill training for retraining gait among chronic stroke survivors: A randomized controlled study. Ann Phys Rehabil Med. 2016; 59: 235-241.
29. Bang DH, Shin WS. Effects of robot-assisted gait training on spatiotemporal gait parameters and balance in patients with chronic stroke: A randomized controlled pilot trial. Neuro Rehabilitation. 2016; 38: 343-349.
30. Horak F, King L, Mancini M. Role of body-worn movement monitor technology for balance and gait rehabilitation. Phys Ther. 2015; 95: 461-470.
31. Schenck C, Kesar TM. Effects of unilateral real-time biofeedback on propulsive forces during gait. J Neuroeng Rehabil. 2017; 14: 52.
32. Xiao X, Lin Q, Lo WL, Mao YR, et al. Cerebral Reorganization in Subacute Stroke Survivors after Virtual Reality-Based Training: A Preliminary Study. Behav Neurol. 2017; 2017: 6261479.
33. Boisgontier MP, Beets IA, Duysens J, Nieuwboer A, Krampe RT, Swinnen SP. Age-related differences in attentional cost associated with postural dual tasks: increased recruitment of generic cognitive resources in older adults. Neurosci Biobehav Rev. 2013; 37: 1824-1837.
34. Redfern MS, Chambers AJ, Jennings JR, Furman JM. Sensory and motoric influences on attention dynamics during standing balance recovery in young and older adults. Exp Brain Res. 2017; 235: 2523-2531.
35. Giladi N, Nieuwboer A. Understanding and treating freezing of gait in parkinsonism, proposed working definition, and setting the stage. Mov Disord. 2008; 23: S423–S425.
36. Yang L, He C, Pang MY. Reliability and Validity of Dual-Task Mobility Assessments in People with Chronic Stroke. PLoS One. 2016; 11.
37. Malcay O, Grinberg Y, Berkowitz S, Hershkovitz L, Kalron A. Cognitive-motor interference in multiple sclerosis: What happens when the gait speed is fixed? Gait Posture. 2017; 57: 211-216.
38. Foerde K, Poldrack R, Knowlton B. Secondary-task effects on classification learning. Memory & amp; Cognition [serial online]. 2007; 35: 864-874.
39. Roche R, Commins S, Mara S, et al. Concurrent task performance enhances

low-level visuomotor learning. Perception & amp; Psychophysics [serial online]. 2007; 69: 513-522.

40. Fritz N, Cheek F, Nichols-Larsen D. Motor-Cognitive Dual-Task Training in Neurologic Disorders: A Systematic Review. Journal of Neurologic Physical Therapy. 2015; 39: 142-153.

41. Plummer P, & Osborne MB. What Are We Attempting to Improve When We Train Dual-Task Performance?. Journal of Neurologic Physical Therapy. 2015; 39: 154-155.

42. Patel P, Bhatt T. Task matters: influence of different cognitive tasks on cognitive-motor interference during dual-task walking in chronic stroke survivors. Top Stroke Rehabil. 2014; 21: 347–357.

43. Studer MT, McIsaac T, Whetten B, Fritz N. Advancing the clinical application of dual tasking: Individualizing the cognitive, auditory, visual, and manual distraction taxonomy. American Physical Therapy Association Combined Sections Meeting, San Antonio, TX. February 2017.

44. Cho KH, Lee HJ, Lee WH. Test-retest reliability of the GAITRite walkway system for the spatio-temporal gait parameters while dual-tasking in post-stroke patients. Disabil Rehabil. 2015; 37: 512–516.

45. Tsang CS, Liao LR, Chung RC, Pang MY. Psychometric properties of the Mini-Balance Evaluation Systems Test (Mini-BESTest) in community-dwelling individuals with chronic stroke. Phys Ther. 2013; 93: 1102–1115.

46. Al-Yahya E, Dawes H, Smith L. Cognitive motor interference while walking: A systematic review and meta-analysis. Neurosci Biobehav Rev. 2011; 35: 715–728.

47. Plummer-D'Amato P, Altmann LJ, Saracino D, Fox E, Behrman AL, Marsiske M. Interactions between cognitive tasks and gait after stroke: a dual task study. Gait Posture. 2008; 27: 683–688.

48. Shumway-Cook A, Woollacott M, Kerns KA, Baldwin M. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. J Gerontol A Biol Sci Med Sci. 1997; 52: M232-240.

49. Shumway-Cook A, Woollacott M. Attentional demands and postural control: the effect of sensory context. J Gerontol A Biol Sci Med Sci. 2000; 55: M10-16.

50. Shumway-Cook ONE MORE.

51. Yang L, He C, Pang MYC. Reliability and Validity of Dual-Task Mobility Assessments in People with Chronic Stroke. Tremblay F, ed. PLoS ONE. 2016; 11: e0147833.

52. Menant JC, Schoene D, Sarofim M, Lord SR. Single and dual task tests of gait speed are equivalent in the prediction of falls in older people: a systematic review and meta-analysis. Ageing Res Rev. 2014; 16: 83–104.

53. Muir-Hunter SW, Wittwer JE. Dual-task testing to predict falls in community-dwelling older adults: a systematic review. Physiotherapy. 2016; 102: 29–40.

54. Eggenberger P, Tomovic S, et al. Older adults must hurry at pedestrian lights! A cross-sectional analysis of preferred and fast walking speed under single- and dual-task conditions. PLOS. 2017; 12: e0182180.

55. Altmann LJP, Stegemöller E, Hazamy AA, et al. Unexpected Dual Task Benefits on Cycling in Parkinson Disease and Healthy Adults: A Neuro-Behavioral Model. Wang K, ed. PLoS ONE. 2015; 10: e0125470.

56. Billinger SA, Boyne P, Coughenour E, et al. Does aerobic exercise and the FITT principle fit into stroke recovery? Curr Neurol Neurosci Rep. 2015; 15: 519.

57. Boyne P, Dunning K, Carl D, et al. High-Intensity Interval Training and Moderate-Intensity Continuous Training in Ambulatory Chronic Stroke: Feasibility Study. Phys Ther. 2016; 96: 1533-1544.

58. Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res. 2008; 51: S225-239.

59. Plummer P, Zukowski LA, Giuliani C, Hall AM, Zurakowski D. Effects of Physical Exercise Interventions on Gait-Related Dual-Task Interference in Older Adults: A Systematic Review and Meta-Analysis. Gerontology. 2015; 62: 94-117.

60. Chawla S, Walia M, Behari M, et al. Effect of type of secondary task on cued gait on people with idiopathic Parkinson's disease. J Neurosci Rural Practice. 2014; 5: 18–23.

61. Beurskens R, Bock O. Age-related deficits of dual-task walking: a review. Neural Plast. 2012; 2012: 131608.

62. Menant JC, Schoene D, Sarofim M, Lord SR. Single and dual task tests of gait speed are equivalent in the prediction of falls in older people: a systematic review and meta-analysis. Ageing Res Rev. 2014; 16: 83–104.

63. Montero-Odasso M, Verghese J, Beauchet O, Hausdorff JM. Gait and cognition: a complementary approach to understanding brain function and the risk of falling. J Am Geriatr Soc. 2012; 60: 2127–2136.

64. R. Galletly and S. G. Brauer. "Does the type of concurrent task affect preferred and cued gait in people with Parkinson's disease?" Australian J Physiother. 2005; 51: 175–180.

65. Kemper S, Herman RE, Lian CHT. The costs of doing two things at once for young and older adults: talking while walking, finger tapping, and ignoring speech or noise. Psych and Aging. 2003; 18: 181–192.

66. Chawla S, Walia M, Behari M, et al. Effect of type of secondary task on cued gait on people with idiopathic Parkinson's disease. J Neurosci Rural Practice. 2014; 5: 18–23.

67. Beurskens R, Bock O. Age-related deficits of dual-task walking: a review. Neural Plast. 2012; 2012: 131608.

68. Menant JC, Schoene D, Sarofim M, Lord SR. Single and dual task tests of gait speed are equivalent in the prediction of falls in older people: a systematic review and meta-analysis. Ageing Res Rev. 2014; 16: 83–104.

69. Montero-Odasso M, Verghese J, Beauchet O, Hausdorff JM. Gait and cognition: a complementary approach to understanding brain function and the risk of falling. J Am Geriatr Soc. 2012; 60: 2127–2136.

70. Galletly R, Brauer SG. Does the type of concurrent task affect preferred and cued gait in people with Parkinson's disease? Austral J Physiother. 2005; 51: 175–180.

71. Rosso AL, Cenciarini M, Sparto PJ, Loughlin PJ, Furman JM, Huppert TJ. Neuroimaging of an attention demanding dual-task during dynamic postural control. Gait Posture. 2017; 57: 193-198.

72. Schättin A, Arner R, Gennaro F, de Bruin ED. Adaptations of Prefrontal Brain Activity, Executive Functions, and Gait in Healthy Elderly Following Exergame and Balance Training: A Randomized-Controlled Study. Frontiers in Aging Neuroscience. 2016; 8: 278.

73. Wang X-Q, Pi Y-L, Chen B-L, et al. Cognitive motor interference for gait and balance in stroke: a systematic review and meta-analysis. European Journal of Neurology. 2015; 22: 555-e37.

74. Lee KB, Kim JS, Hong BY, Lim SH. Clinical recovery from stroke lesions and related outcomes. J Clin Neurosci. 2017; 37: 79-82.

75. An HJ, Kim JI, Kim YR, Lee KB, Kim DJ, Yoo KT, et al. The Effect of Various Dual Task Training Methods with Gait on the Balance and Gait of Patients with Chronic Stroke. Journal of Physical Therapy Science. 2014; 26: 1287–1291.

76. Merzenich M. Experience-Dependent Adult Cortical Plasticity. III STEP Conference. APTA. Salt Lake City, UT. 2005.

77. Kleim JA. 2005. Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. III STEP Conference. APTA. Salt Lake City, UT.

78. Gordon Choi Y1, Qi F, Gordon J, Schweighofer N. Performance-based adaptive schedules enhance motor learning. J Mot Behav. 2008; 40: 273-280.

79. Winstein C, Lewthwaite R, Blanton SR, Wolf LB, Wishart L. Infusing motor learning research into neurorehabilitation practice: a historical perspective with case exemplar from the accelerated skill acquisition program. J Neurol Phys Ther. 2014; 38: 190-200.

80. Nepveu JF, Thiel A, Tang A, Fung J, Lundbye-Jensen J, Boyd LA. A Single Bout of High-Intensity Interval Training Improves Motor Skill Retention in Individuals With Stroke. Neurorehabil Neural Repair. 2017; 31: 726-735.

81. Lewthwaite R, Wulf G. Optimizing motivation and attention for motor performance and learning. Curr Opin Psychol. 2017; 16: 38-42.

82. Sarkar M1, Fletcher D. Psychological resilience in sport performers: a review of stressors and protective factors. J Sports Sci. 2014; 32: 1419-1434.

83. Fulk G, He Y, Boyne P, Dunning K. Predicting Home and Community Walking Activity Poststroke. Stroke. 2017; 48: 406-411.

84. Fulk G. Personal communication. 2017.

85. Hurst R. The international disability rights movement and the ICF. Disability and Rehabilitation. 2003; 25: 572-576.

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