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Review Article

Making Balance Automatic Again: Using Dual Tasking as an Intervention in Balance Rehabilitation for Older Adults

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Abstract

The science of balance rehabilitation and fall prevention continue to evolve. At this time, it is well established that balance requires a dynamic and real-time interplay of person to environment to determine the best motor program and monitor where change will most likely be needed [1,2]. It is additionally recognized that the options of balance reactions available in any given task are largely procedural in nature, being automatized and operating primarily on a subconscious analysis of the environment (hand holds, information about surface friction and stability, obstacles, accuracy demands, etc) [3-6]. The science of improving automatized responses, known as procedural memories, is growing and continues to advance in the fields of sports science and, slowly, into rehabilitation. Recently, the evidence for procedural memory training has advanced in sophistication to suggest and ultimately prove that automaticity of a primary motor task can be developed through exposure to massive repetitions (practice) and the forced subconscious processing using dual task interference [7-11]. Sport science is already employing this approach regularly, with training programs that involve basketball players enduring distractions of all kinds to reinforce the accurate retrieval of the skilled movement, regardless of the game-environment context (second basketball to dribble and attend-to, crowd support or opposition, weather, situational pressure). Evidence suggests this application to regain automaticity in primary motor tasks, can be applied to re-learning tasks in rehabilitation as well [10,12]. In all of these applications, coaches, scientists and clinicians employ strategies that involve the introduction of secondary tasks that draw or allocate attentional reserves, leading the nervous system to process a primary task in procedural memory centers. In this article, dual task training infused with balance rehabilitation will be considered for healthcare professionals' efforts to improve balance reactions in older individuals.

Introduction

The societal and financial impact of injurious falls makes fall prevention one of the highest health-related priorities as our population ages. The average cost of medical care after a fall is often cited as $1,300 to $1,800. Normal processes in aging do place an individual at higher fall risk, these being reduced neural conduction velocity, changes in visual acuity, reduced reaction speed, sarcopenia, and others. Along with these normal changes, there is an increased prevalence of Mild Cognitive Impairment (MCI) with aging. Combining the rate of societal aging with (normal) central age-dependent changes of reaction speed or the (pathologic) increased prevalence of MCI, it can be seen that cognitive factors that increase fall risk are both more influential in medical care, than in recent times. Cognitive impairments (normal and pathologic) are tied to fall risk through reduced attention, leading to impaired decrease dual task tolerance, making it easier to see that paying attention when attentional resources are dwindling. It is established that dual task tolerance is clearly related to fall risk [13-24]. It is important for physical therapists, as the primary profession positioned to reduce fall risk, to be cognizant of and improve the sophistication of dual task testing and treatment. For a complete task-specific integration for environmental independence, balance rehabilitation must include full environmental complexities.

Each day, over 10,000 people turn 65 in the United States. With this statistic and the fact that nearly 30% of US residents over 65 fall at least once per year, we are compelled to address all factors that increase fall risk [25]. Combing the average cost of a fall, the incidence of falls, with the significance of cognitive decline, makes this an important variable to impact. This relationship between dual task tolerance and risk for falling, which is linear and clear for the "condition" of aging, is relevant to the epidemic of falls in the elderly, and is a primary issue covered in this article. Noteworthy and related, yet beyond the scope of this manuscript, is the strong relationship to dual task tolerance and functional independence, and many other common diagnoses such as stroke, Parkinson's disease, neuropathy, and Multiple Sclerosis [26-53].

While no single system of the human body can be consistently implicated as causal for most community dwelling elderly falls. Physical Therapists (PTs) are positioned to answer the questions proposed above and find themselves in the crosshairs of fall prevention primarily through improved balance reactions. Physical therapists are movement scientists that measure and observe gait speed,

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measure patients' sense of balance in different sensory conditions, and their ability to change directions. Therapists that employ a comprehensive approach to fall prevention will additionally measure Range of Motion (ROM), strength, endurance, sensation, home environment assessment (among others) in an effort to understand individual risk factors and create an intervention accordingly. Regardless of the specific origin for a person's imbalance, most rehabilitative efforts include direct in-task challenges to sitting, standing and walking balance.

As experts in movement science, measurement of body-system impairments, and the synthesis of impairment to function, physical therapists are well-positioned to be the experts in balance. Practice in reducing fall risk has been and continues to improve in the sophistication toward analyzing and quantifying balance and the environment to patient interaction to maintain balance. Commonly and most comprehensively, this is accomplished through measuring relevant system impairments, task analysis, and functional measures in both static and dynamic balance. Therapists use these measures to rehabilitate underlying impairments in systems, and attempt to intervene directly in the balance aspects functions of transfers, gait, reaching, and bed mobility all commonly involved in falls as well.

How accurately, regularly and proficiently do these experts in movement science analyze the patient to environment interplay and attempt to dissect the cognitive skill required specifically attention. Do physical therapists routinely examine patients' function in complex environments and record their tolerance to distractions, known as dual task tolerance? This consideration of dual task tolerance impacts skill, safety, and efficiency at all levels of function. Sport analysts on television can be heard to referring to the impact of distractions on the football wide receiver who is simultaneously adjusting his motor control of running to track down an errant pass, while monitoring an oncoming defender. As therapists observe patients, they must play the role of the television analyst, by considering the role that fear and cognitive processing play when the older resident of an assisted living facility attempts to sequence her walker and painful right leg in gait while simultaneously attending to a grandchild's conversation. As a whole, the profession of physical therapy is becoming increasingly more skilled and attuned to the cognitive stimuli in comprehensive task analysis, the influence of distractions, and more recently appreciating the multifaceted nature of environment-person interaction. Tasks trained in physical therapy (walking, stair climbing, wheelchair propulsion) provide an ideal opportunity to incorporate distractions, as patients practice mobility skills and experience errors in safety and efficiency.

Dual task is a topic of increasing research interest. In 2006, "dual task" was cited in 178 publications. This increased to 552 citations in 2016 - a greater than 300% increase over 10 years [54]. The rate of increase in publications by PTs and in PT-journals, as well as continuing education courses including the topics of cognition has increased similarly, since 2007. It is a function of this research that screening measures used in clinical practice have evolved to incorporate dual task and cognitive features, allowing for improved recognition of impairments and restoration of function.

The topic of dual task tolerance has reached publications beyond the medical and rehabilitative journals, and into retirement community programming. In a June 2017 article on safety in senior living, Angie Szumlinski, NHA, RN-BC, RAC-CT, BS writes, "Say a resident at risk for falls ambulates in a common area that is distracting. To assess the person's risk, consider what types of distractions might interfere with the president's ability to ambulate safely. Noise, raised voices, other residents calling out, chair/bed alarms, door alarms, telephones ringing, overhead paging, clutter around seating areas, staff moving about with medication carts and supplies are all distractions that require the resident to multi-task while walking.

Even if the resident tries to "tune out" distractions, it isn't always possible. It is likely the resident will listen to other conversations, respond to alarms sounding, turn to respond to their name being called, or will be required to step around items on the floor: This constitutes multi-tasking [55]."

The interaction with the environment, when it comes to maintaining walking, standing, or even sitting balance, cannot be ignored. Functional tolerance of environmental and task-based distractions is one of three parts of this paper. The second part will address what is known and unknown about dual and multi-task tolerance in testing, treatment, and compensation, relating this back to falls in the elderly. Finally, readers can expect to learn about the intentional introduction of distractions in an effort to create a more reliable set of procedural memories that are readily available in the form of balance responses in upright mobility. These three distinct topics should help to advance the field of balance rehabilitation within physical therapy, improving our efforts to maximize the safe function in members of our aging society.

Part 1: Environmental and task interaction: What is dual task and dual task tolerance?

In their 2016 article, McIsaac and colleagues defined dual task as, "…the concurrent performance of two tasks with distinct and separate goals [56]." In the daily mobility of an older adult, the need to hurry to get to a phone, a door, or the bathroom is a complex single task merely adding the element of time as pressure. However, dialing 911 while one walks hurriedly to an injured spouse, or walking while stacking dishes atop one another to more efficiently clear a dinner table would be examples of dual tasks as the activity with the hands is performed concurrently and distinctly from the act of walking. Table 1 lists a sample of daily activities that could be combined with walking, as true dual tasks.

Finally, by way of definition for clarity, walking and speaking on a cell phone is a dual task, but merely carrying a phone that is turned off, is not. The relative success of dual tasking - how well a person can tolerate the addition of a second (or third) task, can be expressed using terms such as Dual Task Tolerance (DTT) or dual task capacity. This capacity can be expressed using the relative success in observational or descriptive terms - and can be quantified

Table 1: Everyday examples of dual task with walking balance.

Retrieving an item from a purse
Cleaning glasses
Recalling a shopping list
Listening intently to a conversation
Pulling a license out of a wallet

$$\text{Dual Task} = \frac{DT - ST}{ST} \times 100$$

Figure 1: Calculating Dual Task Cost.

using the equation for dual task cost, as shown in Figure 1 [56-58]. Dual tasking requires attention. The ability to allocate attention, share resources, and endure more stimuli while concentrating on the relevant information is all included in this skill. Although attention is often identified as an attribute of executive function, it is important to note that tests of executive function have been largely unsuccessful in predicting DTT [57,58]. The reader is directed to the writings of Hart et al., [59], and Lezak and colleagues [60] for more complete descriptions of executive function, as related to metacognitive skills, self-monitoring and self-regulation. These skills are required to successfully implement information gathered when attention is accurately allocated. Practically, people need to be able to safely move through environments while accurately filtering irrelevant stimuli and attending to that which impacts performance. It is important to recognize that priorities both will and should shift during a task, alternating for example between a primary (walk) and secondary (important conversation, route finding, time management, day planning, etc) task at hand. Sometimes a fall occurs when the secondary task either takes up too many resources [61,62] or becomes the main focus, jeopardizing the primary locomotor or balance task (e.g. reaching, stand to sit). The ability to make rapid decisions about where to allocate attention and resources that can be devoted for concentrated function, have been shown to diminish with age. These are well-cited and include changes in nerve conduction velocity, reaction speed, strength and flexibility, as well as the referenced reductions in central resources of attention. These obligatory changes associated with aging are believed to be the mechanisms behind the research findings that have consistently and repeatedly established the fact that dual task tolerance decreases with age and is often a causal factor in many falls. As described above, attention is a complex skill. Attention is located in the frontal lobe of the brain, yet it is simultaneously a distributed skill. McDowd's model of attention with includes four discrete functions, those being: switching, divided, sustained, and selective (Table 2). Each of these capacities are discrete, yet they do have overlapping and dedicated networks in the brain that will be described below in the primary consideration of dual tasking, or divided attention.

Neurophysiology of attention and changes in disease and aging

It is imperative to understand the physiology of attention in adulthood, and in aging, in an effort fully apply what is known about the role dual tasking in fall risk. The neurophysiology of attention serves the function known as dual task or multi-task performance, no matter the nature of the primary task, be it locomotor (e.g. gait or w/c propulsion), manual (e.g. typing), or cognitive (e.g. paying attention to a conversation and a television program). As noted above, attention is a diverse network that can largely be localized to centers in the frontal and parietal lobes. For the purpose and scope of this article, it is important to understand this diverse connectivity or network required to pay selective or divided attention. This network includes extensive connections between the frontal lobe and various sensory-specialty zones (occipital for vision, parietal for perception as well as tactile somatosensation). The connections additionally include deep structures including the thalamus and cingulate gyrus for synthesis and relay [63-67]. These centers are largely regulated by the bilaterally-present Dorso-Lateral Prefrontal Cortex (DLPFC) and the nearby Ventro-Lateral Prefrontal Cortex (VLPFC). It is noteworthy that the DLPFC receives dopaminergic input directly from the substantia nigra, an important caveat to note for those of you working with persons with Parkinson's Disease as some people with PD have lost both the procedural center (basal ganglia) and the attention regulator (DLPFC) [68]. The non-dominant parietal lobe serves as a center for body image, and attention to the spatial relationships of body and environment leading to well-cited neglect syndromes when lesioned [69]. As noted, attention is organized with separate networks is that visual, temporal, or otherwise; and with discrete responsibilities that will be covered more lately of: switching, sustained, divided, and selective.

Table 2: McDowd's Models of Attention.

Selective
Switching
Sustained
Divided

Tolerance for secondary tasks and distractions is an individualized skill, which is partially dependent on the extent to which the primary task is automatic, or well-formed as a procedural memory. A procedural memory serves as a mechanism to more readily store a program or response that must be routinely accessed. A procedural memory may include a cognitive response (memorized mathematical tables or state to capital matches) or a motor program (walking, brushing teeth, ascending a very familiar flight of stairs, using a longtime key and lockset, pulling on a shirt) and the corresponding sensory expectations. These programs may be available for routine movements found in daily life, vocation, or even avocation/sport. Procedural memories, by definition, include subconscious operation largely without full attention on the task. Both the acts of altering an existing as well as forming new procedural memories require learning through some form of implicit memory access. Procedural learning requires two basic ingredients: repetitions and a dual task impetus the latter only being necessary to achieve performance that is independent from access to resources of attention. The process whereby walking became a procedural memory was accomplished through repeating increasingly more complex forms of walking (more and more dual tasks overlaid) activity over and over again until all of the relevant neural systems work together to automatically produce the activity. Fitts and Posner describe these three stages of learning from the entry level and relative novice (intellectual phase) to the learner that can self monitor and see a problem as it is occurring (emergent phase) and finally to the most advanced level, within which the learner prevents past errors and operates with automaticity, known as the autonomous stage. Investigations of procedural memory resilience have a singular common thread, based on the hypothesis that the more well-established a procedural memory is, the harder it should be to distract subjects enough to affect their performance. This resilience is an expression of selective attention, again processed in the DLPFC. The capacity for selective attention is a function of dual task tolerance. Selective attention and automaticity can be observed when a professional basketball player shoots an important free throw while an opposing crowd jeers.

Performing a motor task at optimal skill levels, regardless of the environment, may play a role in success in athletics and life. In the prior example, this could be measured in free throw percentage while playing a "road" game (away from a home crowd) as compared to the same percentage on a home court. Ultimately, what is being tested is the resilience of a procedural memory, in this case the motor control of shooting a free throw, walking briskly, reciting multiplication tables, and brushing your teeth. There are many examples of dual task cost in sports and real-world that reflect selective attention. One of the most well-cited includes a baseball pitcher's efficiency (measured in balls-strikes, batting average, or earned run average) with opponents on base (a distraction being a threat to steal), as compared to no one on base. It is for these reasons that both golf and tennis have rules and protocol for spectators that consider this very element, calling for silence from the crowd during the serve in match play and strokes on the course. High level pianists can perform, speak, interact, sing, change postures, and turn pages all without missing a note. Failures of automaticity can be seen more frequently under the duress of distractions in the form of distracted driving accident rates, incidence of falls or obstacle obstruction while walking and texting on a cell phone. Similarly, the proficiency of an older adult hiker on a well-known pathway that has been regularly traversed for years should be higher than that of novice hikers, regardless of age. The more well-experienced hiker, familiar with the outdoors and of this particular pathway, should be in the autonomous phase of learning, expressed in capacity to make fluid and dynamic environmental assessments (exposed roots, rocks, branches to duck) than novice hikers. Examples of resilient procedural memory can be found in sport (as noted above), in recreation (the example of hiking), and especially in vocations that require rapid and repeated manual task operation (stenographers, chefs, and in assembly-line work) (Table 3).

Under normal conditions, the capacity to build a procedural memory and tolerate distractions is a function of the DLPFC and the network described above. However, co morbid health conditions can affect dual task tolerance as well. Conditions that affect the body may limit access to a well-formed procedural memory. Similar to that distracted basketball player attempting a free throw, patients that have ankle, hip, or back pain, a recent total knee replacement, or reduced sensation due to neuropathy, will be more intolerant to and affected-by distractions. Even with years of repetitions, people that are compelled to change how they move and walk due to weakness,

Table 3: Horak and Mancini Systems of Balance.

Biomechanical constraints
Stability limits/verticality
Anticipatory Postural Reactions
Postural responses
Sensory orientation
Stability in gait

fatigue, pain, poor sensation, or restricted range of motion are unable to use their well-formed procedural memories under these distracted conditions. Imagine the potential change of a small cut on a finger, or even wearing a bandage might have on an expert pianist with a performance tonight. Now, imagine that impact on a 3rd grader who is participating in his first recital.

The process of aging does not affect each person's function (cognition or physical) in the same manner. Life experiences and resources of intelligence built along the way are important considerations, as would physical fitness be on the impact of age-induced sarcopenia. In pathology, such as Mild Cognitive Impairment (MCI), dual task tolerance is measurably reduced. Procedural memories are largely spared in the case of MCI and even Alzheimer's Disease (AD), as the main procedural memory centers of the basal ganglia, cerebellum, Supplementary Motor Area (SMA) are preserved in these conditions. This is not to say that attention (the resource of or appropriation of) is spared in MCI. Dual task tolerance is impaired in aging through similar mechanisms, including the inability to allocate or prioritize attention, filter distractions and selectively attend when competition for attention arises. In contrast to the cases of MCI and AD, intelligence may protect against clinically-detectable DT tolerance loss. The science is imperfect and imprecise on these points, yet it can be stated that having a reserve in intelligence and cognition can afford enough shared resources to more proficiently divide (simultaneous),or decide (allocate appropriate resources through filtering) when faced with dual task demands. Taylor et al measured DT cost included a combination of walking with counting backwards by sevens and naming animals. Interestingly, the fall risk threshold for self-selected walking speed of 1.0 m/s served as an excellent dividing line between normal and cognitively impaired subjects. Overall gait speed and variability in gait speed have been shown to be both effective predictors of subjects' relative cognitive grouping, and in this study, the variability of gait doubled and tripled between single and dual task conditions (reflecting a higher degree of dual task cost) for the MCI and AD groups, respectively. Eggenberger and colleagues studied older and younger subjects' ability to traverse a crosswalk in a timely manner, finding that older adults were indeed more challenged than younger subjects' in efforts to maintain the same walking speed under pressured and distracted conditions.

The findings of many studies support the notion that dual task tolerance reduces with age. In 2015, Clark and colleagues wrote, "fNIRS studies of walking have demonstrated that more complex walking tasks also require heightened prefrontal activity relative to undemanding steady state walking.", noting that prefrontal changes with aging may be a causal link to DT reductions [70]. Lighthall et al., [71] in 2014 discovered through fMRI that some age-related executive control functions could be processed in a nearby area, the Ventro medial Prefrontal Cortex (vmPFC), in a compensatory manner - if challenged to do so.

In addition to the central, primarily frontal-lobe effects of aging, we recognize peripheral changes that influence older adults' attempts to balance for daily needs. As noted above, nerve conduction velocity, reaction speed, sarcopenia, and changes at the level of the joint (stiffness, ROM) influence the timeliness and accuracy of balance reactions. It should be noted, that the central and peripheral changes combined, are enough to explain the changes experienced with aging

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alone. McIsaac and colleagues suggested that dual task intolerance in aging stems from a multimodal sensory processing (speed of conduction) reduction coupled with a loss in executive processes (reaction time and attention) to be among the multifactorial causes, while other authors cite the prefrontal processing dilemma of switching attention, as causal [72-74]. Clearly, these delays central and peripheral in nature would allow for many subtle adjustments at the level of the ankles could be delayed just enough to be expressed as a displacement of the Center Of Gravity (CoG) and a loss of balance, with aging. These insipient losses could have a psychological effect on any community-dwelling individual that would cause some alarm and fear of falling a relevant consideration in this cycle.

In addition to these cited losses that are largely a function of the aging process, both central and peripheral, there is an additional role of the environment and learned nonuse in these losses. Many assisted living facilities are built and designed for the ease of daily routine. The environments themselves limit the need for a resident to actively attend due to predictable flooring, impeccable lighting, and limited distractions. Note again that this is relevant to normal aging, as both persons with MCI and AD have a documented and accelerated loss of DT tolerance, expressed in higher DT cost. Reflective of this being partially a function of learned nonuse, many studies have proven elderly subjects can improve dual task tolerance with training, while others have refuted this claim [75-80]. In their 2010 meta-analysis, Smith et al cited an overwhelming collection of data supporting aerobic exercise as the most successful avenue for improving executive function in aging and preventing DT tolerance losses.

Part 2: Dual task testing, training and the evolution of clinical applications as related to fall

The clinical application of improved appreciation for cognition in physical therapy practice comes largely in the form of dual task testing and training. It should be noted that there has been an enormous amount of research that has been published in the last 7 years, using laboratory tests with headphones, virtual reality environments, and other technological applications. Research remains focused on the tests, measures, and rehabilitative interventions that are commonly used in the clinic. In research and clinical practice, the primary motor task to combine with cognitive testing is ambulation. Testing and training variables to be considered for the secondary task have included: 1) type or "mode" of distraction: cognitive, visual, auditory, or manual [81-83]. 2) Methodology (testing each task as a single-task prior to combining) [84-86]; and 3) considerations of task complexity/novelty and reality (meaning how contrived or reality-based the task should or can be).

As previously shown in Figure 1, the most common mathematical expression of dual task tolerance uses the equation for Dual Task Cost (DTC). Dual task cost is a statistical reflection of change in performance in the primary task from single to DT conditions. Calculating and objectifying DTC is important for scientists and clinicians alike to be able to record baseline and subsequent performance, in an objective manner for purposes of reimbursement, motivation, efficacy, treatment planning, and home exercise programming. Well-established tests that are intended to reflect DT cost 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 components as developed by Shumway-Cook and colleagues [87,88]. Respectively, these versions superimpose 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. Additionally, using McIsaac's definition of DT, "…the concurrent performance of two tasks with distinct and separate goals.", the TUG-m test may not truly be examining a secondary task, but rather just a more complex version of the TUG. Readers are directed to other references for discussions of other less-frequently applied measures of dual task performance, including the Walking and Remembering Test, the Stops Walking While Talking Test, Multiple Tasks Test, the Trail Making Test, and versions of the Stroop Test [89-93].

There are emerging DT testing strategies that have potential yet have not been fully vetted in research. Those tested in clinical settings include overlaying distractions during the Four Square Step Test, during Sensory-Organization Testing (SOT), Clinical Test of Sensory Integration in Balance (CTSIB), and timed or sensor-based measurements during ADLs or in gait. Referenced earlier is the recent article by Eggenberger and colleagues used a Virtual Reality (VR) street crossing test with older adults, comparing both their preferred walking speed and fast walking speed in terms of dual task cost. Distractions in the VR environment included calculations and mental operations such as listed above. The authors found that older adults' fast walking speed under timed (pressured) conditions to cross the street was more susceptible to distractions than self-selected or preferred walking speed. This was evidenced by higher dual task cost in the "pressured" or fast-paced trials. One consideration that was not cited in the discussion of this article includes the more procedural nature of preferred walking speed, making it theoretically less susceptible (more resilient or DT tolerance expressed in lower DT cost) to distractions. Many research methods include an overlay of common psychological tests (Trail Making and Stroop) in an effort to systematically study the effects of dual task cost on physical and cognitive performance, as noted and referenced above [94,95]. Versions of the Stroop have even been studied with some success in efforts to recognize prodromal PD or AD [96]. The Auditory Stroop [97] requires subjects to inhibit misleading cues in attempt to process the correct response (selective attention), while the Trails B tests, requires alternating attention, as subjects switch back and forth between a numerical to alphabetical stimulus in sequence. Most research applications of dual task testing now employ a methodology of testing a primary motor task in solitude (single task mobility); testing performance on a structured distracter in solitude (digit span recall Golino, for example); then examining the dual task effect on each considering more than just the impact of the combination on the mobility task. In this evolution, the future of dual tasking is likely to soon include more wireless gait analysis, for more objective parameters of gait in the single and dual expressions, as this is presently being explored on a clinical basis.

As noted, a more recent consideration of dual task testing and examination includes the recognition of the types of distractions, or dual task modalities. This foray into subsets of distraction tolerance started in 1997, when Shumway-Cook and Woolacott studied the effects of distractions on quiet standing balance. The authors examined the effect of different types of distractions on postural stability, by combining posturography with analyzing sentence completion and line orientation. Results indicated that tolerance to

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distractions could be measured (posturographic changes) and were additionally predictive of fallers vs. non-fallers in the study. Again, it is necessary to mention, yet beyond the scope of this article to review the four distinct modalities of distractions that are now recognized in research methodology and clinical application include: cognitive, visual, auditory, and manual distractions. Table 2 categorizes the four modalities and lists examples of each modality in daily function.

In summary, the science of DT testing is an imperfect science that includes many efforts that are possible in the laboratory, but impractical in the clinic. Readers are directed to emerging research methods for DT testing strategies (along with the associated mode of distraction) are listed here: sentence completion (cognition or auditory), virtual environments (visual), mathematical calculations (cognitive), spelling words in reverse (cognitive), recalling a list of objects presented (auditory), object recognition and inhibition (visual), timed reactions to a stimuli presented by word (visual or auditory), or bimanual fine motor tasks such as a coin transfer (manual).

Dual task dosage

There is no prescription for dual task introduction much less when it is to be integrated with a nearly equally amorphous shape of balance rehabilitation. The principles of neuroplasticity apply here, through the commonality of learning (permanent changes in the brain). Those principles, from the seminal article about neuroplasticity by Kleim and Jones include task specificity, intensity, meaning to the learner (salience), complexity, and difficulty.

Considering the aforementioned concept of task specificity in the science of dual task, each modality of distraction must be represented in a thorough examination combining balance and a structured distraction. In keeping with the McIsaac and colleagues' definition of dual task, the distraction should be discrete and therefore measurable by itself. A true positive screen or quantified intolerance of DT should include the primary balance task by itself; then, the distracter measured by itself; then a measureable performance of each when combined.

As noted, dual task capacity can be screened and then further examined to quantify DT tolerance in a modality-specific manner. Training or rehabilitation follows the measured intolerance. Interventions in DT often revolve-around a primary task of ambulation. Common applications of distractions overlaid on these primary tasks may include some secondary tasks that are challenging by themselves, such as subtracting by serial 7s, spelling words in reverse, or recalling words presented prior to a difficult task. As noted above, contemporary dual task literature recognizes the benefit of measuring performance in the single cognitive task, prior to the dual task combination [98,99]. Clinical and laboratory examples of interventions might include: asking patients to perform mathematical calculations, spell words backwards, name state capitals. While these tasks might be effective in screening or testing for DT tolerance, they may not truly reflect the concept of task specificity as they would have little resemblance to real world dual tasking. Clinicians and scientists alike, are increasingly applying more real-world applications in DT, including: dialing or texting on cell phones; pulling specific items from a purse, wallet, or pocket; recalling information delivered prior-to and after a primary task (such as in the WART); utilizing obstacles for visual distraction; and overlaying relevant (real world) auditory distractions (such as the Auditory Stroop) during the motor task [100].

Dosage must not only consider "what" in terms of task specificity, interest and difficulty, but "how much" in terms of intensity, more so than volume (repetitions, duration or frequency). Neither balance rehabilitation or dual task training have a defined prescription as do strength, muscular endurance, and cardiovascular training in the American College of Sports Medicine's guidelines for strength or endurance training in terms of percentage of 1-repetition maximum or by heart rate guidelines. The "how much" in balance rehabilitation is seen through losses of balance, near falls, and parameters that are not only harder to quantify, but are also very person-specific as to the willingness to be challenged, given the inherent threat of instability. The reader is directed to Table 3, for a consideration of how to provide an individualized prescription of challenge, that includes some input and autonomy from the learner.

Part 3: Rehabilitation of balance as an automatic function

Balance rehabilitation has well-studied efficacy. A comprehensive description of the vast array particular techniques in balance training and progression are beyond the scope of this article. Variables to grade the difficulty of balance interventions include, yet are not limited to: reach, load, and dynamic tasks; varied sensory conditions including compliant surfaces, eyes closed, head motion, direction changes, limited bases of support, obstacles, reaction speed and accuracy demands, as well as biomechanical (force and range of motion) expectations. Some of the more dual task-relevant considerations in balance rehabilitation include: static environmental complexities (changes in terrain, surface heights, friction, obstacles); dynamic environmental (pedestrian traffic); personal effects (wallet, purse, backpack); and ambient environmental (visual and auditory stimuli) - requiring either momentary attention or interaction. Dual task training in rehabilitation of balance can lead to improvements in each of two mechanisms: 1) dual task tolerance and 2) improved primary motor (balance reactions) through automatization. Many research studies support this concept and have expressed subject improvements through lower dual task cost after intervention or training. This concept of improved DT tolerance is often referred to as automaticity [101-103]. This effect follows most rehabilitation principles in which the subject or patient would experience a statistically significant reduction in DT cost. As noted, most research involves combining ambulation with a secondary task and has only recently employed measurement of the secondary tasks in the methods. It is only through measurement of both (primary and secondary), that an analysis of prioritization and attention shift can be made. These research interventions and rehabilitative processes include a degree of intensity, often with a speed-accuracy tradeoff while introducing greater degrees of loading, for a sufficient stimulus. Combining the scale of practice with this level of difficulty, loading to the point of overload, is consistent with two of the seminal principles of neuroplasticity, being repetitions and intensity. It is also notable that results have been mixed in senior subject research. Ruffieaux and colleagues' meta analysis included nearly 1000 studies, pared-down to include only those that compared young and older subjects. The authors' findings included improvements for both age groups in DT cost with training, both for primary and secondary task considerations.

They reported no age difference for DT cost in the primary task for 35% of the studies, and no difference for the secondary task in 70% of the studies. A majority of studies have found improved automaticity in efforts to measure the anticipated improvements in dual task tolerance. There are exceptions to this finding, when measured by primary motor automaticity proficiency and reaction speeds.

The mechanism, by which individuals become more dual task tolerant, may follow a desensitization or habituation-like model. This would be similar to the process in vestibular rehabilitation, conducted by exposing patients to tasks and environments that systematically provoke their symptoms to a controllable level. In the case of dual tasking for balance rehabilitation, a controllable level (the "dosage" of distractions combined with balance demands) would be one that causes clear interference with the primary task, evidenced by greater sway, pathway deviation, reduced gait speed, etc. However, the level of dosage has a personality influence, speaking to the person-specific tolerance of being challenged. Distracted balance intervention can be taken "to" a challenging level, yet not "beyond" to the point of subjecting the patient to the level of difficulty that causes fear or expectations of self-harm. In other words, patients should not need to be become angry about the experience, or operate at a level that would cause a fall or even near fall. Abernethy and colleagues wrote, "The *dual-task paradigm* (or methodology) provides information on "the automaticity, hemispheric locus and structural independence of processes hypothesized to underlie the production of skilled performance." Additionally, McIsaac and colleagues' 2015 publication of a dual task taxonomy supports the concept that task novelty (limited exposure leading to poorly-formed procedural memories) as a prime consideration in determining relative task difficulty and appropriate "loading" for rehabilitative prescription.

As Merzenich and Kleim [101,102] suggested at the III STEP conference in 2005, 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." Additionally, persons experiencing this level of challenge will improve their accuracy of awareness. 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 [102,103].

Compensation and prioritization for non-responders

Most rehabilitative interventions have a set of known characteristics that describe "responders", people who will show the greatest change when this technique/approach or apparatus is integrated into their treatment plan. Some patients should not (don't need) and cannot (degree of impairments, motivation, personality, capacity) respond to dual task training. When a patient proves less than responsive to an intervention, therapists do have an alternative, that being compensation. Compensation can be directed at the patient or caregiver level. Patients can learn to compensate by being trained to recognize dual task situations and either avoid them, or prioritize-through. Prioritization decisions can be made for vigilance (self safety in mobility) or alternatively for social or vocational reasons. Sometimes, a conversation is prioritized over the need to continue walking (verbal or text communication). Just the same, a vocational prioritization could be made at an assembly-line to ensure the accuracy of the manual task (product) that is being created, at the sacrifice of attention on balance; or on the basketball court and football field when a shot in basketball or a catch in football become more important than the final landing position or risk to the body.

Prioritization can be a compensatory strategy that can be implemented in some non-responders to DT, when continuing to engage in a primary motor task yet recognizing tendencies of distraction, could lead to a fall. Prioritization may include an active effort to filter (ignore) less-important sensory stimuli competing for attention, for greater concentration on and proficiency in the primary task. However, effective prioritization could alternatively include stopping the primary task (stop walking) in an effort to stay safe when distracted. These compensations of behavioral modification through education - have limitations as well. An individual's ability to compensate in a threatening environment (high fall risk due to DT conflict) relies upon their abilities to: 1) recognize the threat (environmental stimuli or task requirement overload) in a timely manner, prior to error 2) correctly prioritize according to the task and environmental demands (safety often being at risk) and 3) to strategize under stress which includes a capacity to make and carry-out an effective plan to prioritize despite fear and anxiety.

These three steps (recognizing, prioritizing, strategizing) do require some complex executive control, most notably, the skills of self monitoring or awareness. For older adults, the decision of prioritization may come down to gait speed to get to the phone before it stops ringing, to concentrate on bladder control or left foot drop tendencies; or a choice to attend to either the conversation of a grandchild or the sidewalk inconsistencies in a system that cannot afford to allocate attention to both. In any of these dilemmas, the decision assumes that there is recognition, "Which one is more important to me?" However, the incontinence, foot drop, missed phone call, or fall is not always rationally chosen. Often, the person engaged in dual task conflict does not have full awareness of the choice and does not consciously prioritize. Readers are directed to other works for greater explanation of the levels of awareness, and notable changes with pathologic aging in frontal lobe impairment, neglect syndromes, and dementia.

Dual task studies that consider prioritization cues as an intervention suggest that prioritization is like most any form of feedback in motor learning. Patients appear to be most well-served in receiving a varied schedule of cues and autonomy, some trials being cued to attend to the distraction, sometimes cued to the primary task, and other times given autonomy without cues.

Summary and Clinical Applications

The most clear and resounding support for dual task interventions come directly from the DT literature that supports the predictive nature of DT intolerance, the trainability of distractions, and the notable advances in motor learning, and neuroplasticity using constraints of distractions and intensity. Therapists reading this paper may benefit from the following bullet points in an effort to apply these concepts when rehabilitating their imbalanced older adults:

- Consider the patient's relative experience with the balance challenge/level of difficulty for insight to their relative level of automaticity and timing of adding a distraction. The degree of how novel a task is to the learner (obstacles, speed, carrying a package all complex single tasks that could be novel or experienced) will influence the capacity and appropriateness to dual task. Will distractions interfere with motor learning or re-learning?

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- Consider the patient's underlying comorbidities and physiology behind the imbalance. Complications such as weakness, neuropathy, macular degeneration can influence rehabilitation potential. Beyond limitations, it is important to consider what strengths each individual has that could be utilized more fully.
- Consider this individual's personality and individual tolerance of error (will the patient improve or become more frustrated by the DT loading).
- Specificity matters in the examination and subsequent treatment of both balance and dual task interventions. Exposure to one modality of DT condition should not be expected to transfer to skill (tolerance) in another [104].
- Intensity matters. For repetitions to matter, they must continue to progress and be of sufficient challenge to offer a therapeutic dosage, a stimulus for recovery.

The science of balance rehabilitation and fall prevention continues to mature. It is widely accepted that balance reactions are procedural in nature, being automatized and operating on a subconscious level, leaving retraining to be a combination of mass practice, and exposure to a multitude of possible conditions (speed, surface, base of support size and center of mass movement (static, dynamic, or reaching), load, posture, etc). The science of procedural memory training is growing and continues to advance in the fields of sports science and, slowly, into rehabilitation. The theory of procedural memory training has overlap with that of balance training and is additionally advancing in sophistication. Procedural memory training involves forcing automaticity of a primary motor task through exposure to massive repetitions (practice) and the forced subconscious processing using dual task interference.

This approach is becoming more widely used in sports, in an effort to improve the automaticity of high level skills in primary motor tasks. An industry of coaching, products, games, and applications have been developed in an effort to enable athletes to be more tolerant of distractions and more consistent, predictable, and reliable in their motor performance regardless of environmental complexities. In rehabilitation (stroke, balance, Parkinson's Disease), therapists are beginning to adopt this model of intentionally introducing tasks that cause patients to allocate attentional reserves to secondary tasks in an effort to require that the nervous system process a primary task in procedural memory centers.

For the interventions to be impairment and person-specific, as well as to be successful in inducing carryover, there must be advances in measurement. Screening and testing for specific DT losses is a critical element needed in the rehabilitative design, be the goal for greater tolerance of distractions, or improved automaticity of balance reactions. From accurate measurements, further sophistication in the type, time, frequency, and intensity can be coupled to create a dosage that is specific to impairments.

Future Directions: Integrating Technology and Upcoming Research

Is the science of balance rehabilitation for older adults as sophisticated as it can be? Where will we find the next avenue for improvement technology (virtual reality, body-worn sensors, gaming); imaging, or even brain stimulation? Is it possible that we are not using sufficient intensity in balance rehabilitation? As suggested in this paper, the science and practice of balance rehabilitation has room for improvement through integrating dual task interventions. Dual task rehabilitation in balance is an untapped opportunity to more fully improve patient function through the reaction speed, accuracy, tolerance of distracting environments, and awareness of unsafe task demands.

The importance of preventing falls is well-established, from a clinical, financial and social vantage. The relationship between fall risk and attention is also clear and is no longer refuted. The importance and novel contribution of this article lies in the logical progression through three salient questions posed in the introduction that can now be answered in the affirmative to prove that balance training with dual task overlay, has clinical efficacy.

To reiterate, these questions, all answered affirmatively with citations, were:

1. Can balance be improved or re-trained in older adults that are at risk for falls?
2. Are balance reactions procedural memories, following well-established best techniques to regain automaticity by speed and accuracy?
3. Would retraining balance reactions under dual task conditions be more effective than balance training by itself?

To say "yes" to each of these questions, however, is not enough. There is MUCH more work that needs to be done to improve the sophistication and fidelity of testing, as well as the clinical application of meaningful, intense treatment.

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