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Motor-Cognitive Dual-Task Training in Neurologic Disorders: A Systematic Review

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Abstract

Background and Purpose—Deficits in motor-cognitive dual-tasks (e.g., walking while talking) are common in individuals with neurological conditions. This review was conducted to determine the effectiveness of motor-cognitive dual-task training (DTT) compared to usual care on mobility and cognition in individuals with neurologic disorders.

Methods—Databases searched were Biosis, CINAHL, ERIC, PsychInfo, EBSCO Psychological & Behavioral, PubMed, Scopus, and Web of Knowledge. Eligibility criteria were studies of adults with neurologic disorders that included DTT and outcomes of gait or balance were included. Fourteen studies met inclusion criteria. Participants were individuals with brain injury, Parkinson's disease (PD) and Alzheimer's disease (AD). Intervention protocols included cued walking, cognitive tasks paired with gait, balance, and strength training and virtual reality or gaming. Quality of the included trials was evaluated with a standardized rating scale of clinical relevance.

Results—Results show that DTT improves single-task gait velocity and stride length in PD and AD, dual-task gait velocity and stride length in PD, AD and brain injury, and may improve balance and cognition in PD and AD. The inclusion criteria limited the diagnostic groups included.

Discussion and Conclusions—The range of training protocols and outcome assessments in available studies limited comparison of the results across studies. Improvement of dual-task ability in individuals with neurologic disorders holds potential for improving gait, balance and cognition. Motor-cognitive dual-task deficits in individuals with neurologic disorders may be amenable to training. **Video Abstract available** for additional insights from the authors (See Supplemental Digital Content).

INTRODUCTION

Impairments in both mobility and cognition are common in many neurologic conditions, making previously automatic movements more attention demanding.¹ Divided attention, the ability to respond to multiple stimuli simultaneously,^{2–3} is frequently affected more than

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other domains (e.g. sustained attention).⁴ Divided attention is necessary to successfully perform two tasks concurrently (i.e., dual-tasks), such as a cognitive and a motor task (e.g., walking and talking). Deficits in divided attention and dual-task (DT) ability appear linked to impairments in functional mobility in traumatic brain injury (TBI),^{5–6} acquired brain injury,⁷ multiple sclerosis (MS),^{8–9} Parkinson's disease (PD),^{10–11} stroke,¹² and Alzheimer's disease (AD).¹³

The addition of a cognitive task to mobility tasks to gait or balance has been shown to amplify gait variability in individuals with neurologic disorders. Indeed, under DT conditions, individuals with PD¹⁰ and MS⁸ significantly increased swing and stride time variability, compared to controls. During balance DTs, individuals with MS demonstrated greater postural sway¹⁴ and sway velocity variability¹⁵ than controls. Impairments in divided attention may prevent individuals from allotting appropriate attentional resources to balance and gait, reduce adaptability to challenging environments such as obstacles and uneven paths, and may contribute to fall risk in PD,¹⁰ AD,¹³ and MS.¹⁶

Despite documented deterioration in gait and balance under DT conditions, there are few intervention studies that address this deficit. Available studies are marked by variability of training type and duration. Case studies in mild¹⁷ and severe TBI,¹⁸ utilizing dual-task training (DTT) have reported improvements in balance,¹⁷ gait speed,¹⁸ and DT tolerance.^{17–18} Similarly, DTT improved balance during cognitive activities to a greater extent than mobility training alone in healthy individuals.¹⁹ The purpose of this systematic review was to examine the literature to determine the effectiveness of DTT on mobility and cognition compared to usual care in individuals with neurological disorders.

METHODS

Data Sources and Searches

The search terms “nervous system disease(s) OR neurologic disorder(s)” with “rehabilitation OR intervention” and “dual task(s) OR divided attention OR multi task(s)” were applied to the title, abstract or index term fields. These search terms were directed to the following databases: Biosis, CINAHL, Cochrane, ERIC, PsychInfo, EBSCO Psychological & Behavioral, PubMed, Scopus, and Web of Knowledge. All databases were searched from their inception until January 19, 2014. Two investigators independently screened the titles of the publications identified; if a title potentially met the inclusion criteria, or if there was inadequate information to make a decision, a copy of the article was obtained. Additionally, the reference lists of retrieved articles were searched for potential studies that may have been overlooked or absent from databases.

Study Selection

Figure 1 outlines the number of references considered at each state of the selection process prior to confirming the included trials. A total of 14 identified studies^{20–33} were eligible for inclusion; excluded study details are shown in Figure 1. Inclusion was restricted to studies of adults (>18 years old) with a central neurologic disorder diagnosis, who received motor-cognitive DTT, and were assessed on outcomes of mobility (i.e., gait, balance) or mobility

and one domain of cognition. Due to the paucity of training studies, repeated measure designs were included along with randomized controlled trials (RCTs).

Data Extraction & Quality Assessment

Data were independently extracted from the included trials by two authors and recorded on a standardized spreadsheet that included sample sizes, trial settings, population characteristics, intervention details, and study results. In one trial,³³ there was insufficient information on outcomes and study population; the authors were contacted, but we did not receive a response. As the included studies focused on motor-cognitive DTT, the primary outcome of interest was mobility, including single and dual-task gait velocity and stride length (i.e. one temporal and one spatial measure) or balance, while the secondary outcome of interest was cognitive performance. All outcomes were assessed at the conclusion of training and compared to either usual care (exercise or null – no treatment) or baseline (in the case of repeated measures designs). Due to the wide variation in study outcomes, cognitive and balance measures were not limited to one outcome measure alone; rather all measures used were assessed. The methodological quality of each study was independently evaluated, using the 5 criteria recommended by the Cochrane Back Review Group.³⁵ This scale evaluates criteria relevant to physical therapy practice and is suitable for the evaluation of neurologic clinical trials. (Table 1). Presently, there are no established cutoff scores for high and low quality studies with this tool.

Data Synthesis & Analysis

Two independent raters synthesized the data in a standardized table including study design, participant characteristics, intervention, comparison interventions (if present) and all outcome measures. (Table 2). Since more than 30 different outcome measures were utilized as primary and secondary outcomes, we analyzed the effectiveness of DTT on single-task gait, dual-task gait, balance, and cognition to better examine the results across studies. In studies presenting full data, raw data was extracted to derive standardized mean differences in the case of RCTs and mean change in the case of repeated measures trials as well as 95% confidence intervals for report in a forest plot.

RESULTS

Study Characteristics (Table 2)

Of the 14 included studies, three were RCTs^{20–22} and 11 were repeated measures designs.^{23–33} All studies were conducted in an outpatient setting. The experimental groups sample size median (IQR) were 14(5.5), age of 69.5 (11.5) years, and a male-female ratio of 9(2.5): 7(11.5). In studies with control groups, the sample size was 12(6.3), age 72.3(11.1) years, and male-female ratio of 8.5(3): 8.5(10.5). Seven studies enrolled greater than 20 total subjects.^{20–21, 25–29, 32} Among the 14 studies, 12 different DTT protocols were described; three used single-sessions of cueing^{23–24, 29} to improve gait parameters during DT gait, seven described multi-session training including various cognitive tasks paired with gait^{20,22,28, 30–31} or balance/strength tasks,^{25–26} four employed virtual reality (VR) or gaming,^{21,27,32–33} and four combined DTT with additional therapies (balance^{20,33} or aerobic exercise).^{25–26} Over 35 outcome measures were used to assess the effect of DTT, including

more than seven different tasks to assess DT gait. Table 2 outlines the DT protocols and outcomes measures; here we describe the effect of DTT on the primary outcome measures of mobility (gait and/or balance) and secondary outcome measure of cognition.

Effect of DTT on single-task gait—Spatiotemporal gait parameters (e.g., velocity, stride length) were measured using 3D motion capture, 2D kinematics and the GAITRite electronic walkway.

Parkinson's disease: Compared to both null controls and controls participating in general exercise, individuals with PD who had DTT demonstrated significantly increased single-task gait speed and stride length^{23–24,32} which were maintained at follow-up. Gait endurance also improved, following training with a significant improvement on the 6 Minute Walk Test.³² In test-retest designs, individuals demonstrated improvements in walking speed,^{28–29, 31} step length,²⁹ step amplitude,³¹ and cadence.³¹

Alzheimer's disease: Measures of single-task gait were reported in only one study in individuals with AD; Coehlo et al.²⁶ reported significant improvements in stride length (between group difference 5cm) with an effect size of 2.07 (95%CI: 1.08–2.93) (Figure 2) compared to null controls.

Brain Injury: Single-task gait was not assessed in either of the studies including individuals with brain injury.

Effect of DTT on balance—While one study assessed center of pressure (COP) during the Sensory Organization Test (SOT),²¹ others analyzed COP measures in various single-task and DT conditions,^{25,33} while another²⁵ utilized the Berg Balance Scale (BBS) to examine static and dynamic balance.

Parkinson's disease: Yen et al.²¹ demonstrated a significant improvement on conditions 5 and 6 (eyes closed on an unstable surface and eyes open on an unstable surface with visual surround) of the SOT in the treatment groups over the null control group, but no differences between the two treatment groups (VR vs. conventional balance training). Mirelman et al.³² measured balance indirectly with the Four Square Step Test and noted significant improvements following training that were maintained at follow-up. Conversely, Rochester et al.³¹ measured balance with tandem stance time and found no significant improvement following training.

Alzheimer's disease: de Andreade et al.²⁵ measured balance with the BBS, and demonstrated a large effect size of 1.67 (Figure 2) compared to the null control group (between group difference 4.9 points). Anterior-posterior and medial-lateral COP measures were recorded in quiet stance; with the intervention group demonstrating a reduction in sway while controls had increased sway.

Brain Injury: Although measured, values for quiet stance were not reported by Sviestrup et al.³³ and queries to the author received no response. Improvements on the Community Balance and Mobility Scale were reported for both the conventional exercise group and VR

exercise group;³³ however, two of four null control participants also demonstrated large improvements on the Community Balance and Mobility Scale, and no statistics were reported.

Effect of DTT on cognition—Several studies measured the effect of DTT on domains of cognition including memory, processing speed and attention.

Parkinson's disease: Following cognitively challenging virtual reality training, Mirelman et al.³² reported significant improvements on the Trail Making Test, which evaluates mental flexibility and processing speed, and participants made 31% fewer errors on a serial subtraction task compared to baseline.³²

Alzheimer's disease: After DTT, large improvements on the Frontal Assessment Battery were noted by de Andrade et al.²⁵ and Coehlo et al.²⁶ (effect sizes of 1.96 and 3.07, respectively)(Figure 2), compared to a null control group (between group differences 3.9 points and 6 points, respectively). Conversely, Schwenk et al.²⁰ found no significant differences in cognition as measured by the Trail Making Test following training, compared to a general exercise control group.

Brain Injury: Evans et al.²² reported no significant treatment effect on cognitive performance following DTT (effect size -0.59) with the Memory Span and Tracking Task (between group difference -4.75 points) or the TEA Telephone Search while Counting task (a dual-task) compared to a null control group.

Effect of DTT on ability to dual-task—The most commonly assessed outcome measure across studies was ability to DT during gait, although several examined ability to DT during quiet stance.

Parkinson's disease: Compared to null controls, individuals with PD had significantly improved DT gait speed and stride length,^{23–24,32} maintained at follow-up.³² In test-retest designs, there were also significant improvements in DT gait speed and ^{28–31} stride length,^{29–30} maintained at follow-up.³⁰ Interestingly, Yogev-Seligmann et al.²⁸ reported improvements in gait speed and stride time variability during an untrained DT, suggesting that transfer of training might be possible.

Training effects in DT gait were noted even after short-term training programs. A single 30 minute session of DT training^{23–24} and three 30-minute sessions of DT training,³⁰ resulted in significant increases in stride length and gait velocity that were maintained at a delayed retention.

Yen et al.²¹ reported improvements in DT balance during conditions 5 and 6 of the SOT in both the VR group and the conventional balance group, whereas individuals in the control group declined in these conditions.

Alzheimer's disease: A common measure of DT ability during gait is the calculation of dual-task cost (DTC), which determines the specific effect of the secondary task on the primary task of walking.

$$\text{Dual Task Cost (DTC)} = [(\text{dual task} - \text{single task}) / \text{single task}] \times 100$$

Following DTT, individuals with AD demonstrated significantly reduced DTC for both velocity and stride length compared to the control group, where DTC was unchanged.²⁰ This held true for DT walking when the secondary task was addition or subtraction.²⁰ Similarly, Coehlo et al.²⁶ reported significant improvements in DT stride length with an effect size of 1.62 (between group difference 6 cm) (Figure 2).

Brain Injury: Gait outcomes were not reported by Sviestrup et al.³³; however, Evans et al.²² reported significant improvements in DT gait speed with an effect size of 1.52 (between group difference 6.11s) (Figure 2).

A meta-analysis was not undertaken due to heterogeneity among the identified studies. The trials included variable treatments, disparate disability levels, methodological heterogeneity of the DT training protocols, and vastly variable treatment duration (range = 30 minutes to 24 hours). Given this variability, it was not possible to conduct a meaningful meta-analysis.³⁶ The mean changes (for repeated measures trials), mean differences (for clinical trials), treatment effect sizes and associated 95% confidence intervals for the individual trials are presented by outcome assessment and comparative treatment in Figure 2. Effect sizes > 0 indicate an outcome favoring the DTT group, while effect sizes < 0 indicate an outcome favoring the comparison group.

DISCUSSION

The primary goal of this systematic review was to examine the evidence, supporting efficacy of motor-cognitive DT interventions for individuals with neurologic conditions. This review found that physical therapy interventions, regardless of method, targeting DTT resulted in improvements in single and DT walking and modest improvements in balance and cognition.

Effectiveness and Clinical Recommendations

A formal analysis of frequency, duration and intensity of DT therapies was not undertaken as these characteristics were either highly variable or not included. In studies demonstrating large effect sizes in Figure 2, the frequency, intensity and duration of therapies ranged from a single 30 minute training session^{23–24} to 3 hours/week for 16 weeks.^{25–26} Thus, generalization of these results to the clinic is challenging. There were only three small RCTs in this review;^{20–22} the majority of the studies were repeated measure design studies, which precluded the use of the PEDro scale,³⁴ a common assessment for RCTs. The clinical rating scale was included to measure the clinical usefulness across studies.

Small sample sizes, heterogeneity of the interventions and the outcome measures used further limits generalization of the results. Within diagnoses, differences in the disease status of those enrolled further complicated comparison of individuals with similar functional levels. Twelve different DT interventions were presented across the 14 studies. Thus, clinical recommendation of a single DTT protocol is challenging. Many of the interventions lacked control groups and evaluator blinding, potentially biasing the results toward a benefit with DTT. It is clear that further research is needed to standardize both DTT protocols as well as outcome measures sensitive to change due to such programs in neurologic diagnoses.

Cognition

Prior studies of DT have discussed the contributions of cognition to DT deficits in PD,^{10,37} healthy elderly,^{38–39} elderly adults with cognitive impairment⁴⁰ and MS.⁸ This review yielded mixed results on the effect of DTT on cognition. While several studies reported improvements,^{25–26} others reported no improvement²⁰ or declines.²² Mirelman et al.³² also reported a relationship between the change in the Trail Making Test score and DT gait speed. Taken together, these results suggest the importance of selecting cognitive outcome measures that are within the domain trained and further exploring the relationships between these cognitive measures and changes in mobility measures.

Training in Other Populations

Elderly Adults—DT deficits similar to those of neurologic conditions have been described in elderly adults.³⁹ Following DTT for 10–12 weeks, healthy elderly demonstrated improvements in cognition on the Stroop test,⁴¹ reaction time on a lower extremity motor task,^{42–43} Community Balance and Mobility Scale⁴³ and reduced fear of falling.⁴² In elderly adults with a history of falls, DTT for 6 weeks resulted in greater improvement in memory performance than controls who received only walking training.⁴⁴ In elderly adults with balance impairment, 4 weeks of DTT produced improvements in cognition on the Stroop⁴⁵ and both single and DT walking.^{45–46} Interestingly, variable training (i.e., instructions to prioritize either the motor or cognitive task) was more effective for improvement of mobility and cognitive outcomes under DT conditions than fixed-priority or single-task conditions,⁴⁵ and only those who experienced variable training maintained the gains in DT performance at a 12-week follow-up, while those who experienced fixed-priority training, showed initial benefit that was not maintained at follow-up.⁴⁵ This variable-priority effect has been noted in cognitive-cognitive DT training programs of healthy adults, where individuals trained with variable-priority instructions learned tasks faster and performed better than those who received fixed-priority instructions.⁴⁷

A systematic review exploring the use of DTs to identify elderly fallers was inconclusive,⁴⁸ but suggested that DTs may have added benefit in the assessment of fall prediction and should be studied further. Moreover, in an exploration of gait, falls and cognition, Segev-Jacobovski et al.⁴⁹ concluded that combining motor and cognitive therapies should be included in clinical practice to improve mobility and reduce safety in older adults.

Stroke—Individuals with chronic stroke have demonstrated improvements in mobility and cognitive outcomes following DTT. After a four-week motor-motor DTT program, Yang et

al.⁵⁰ reported significant improvements in single and DT walking compared to a null control.

Limitations

Despite documented DT deficits, there is a paucity of motor-cognitive DTT data for many neurologic disorders. Indeed, many populations are not represented in the DTT data, most notably stroke, MS and Huntington's disease, which have known cognitive and motor deficits. Although several case studies^{17,18} examined DTT in individuals with neurological deficits, there is a deficiency of RCTs in this area. Thus, we included repeated measures designs, several of which lacked control groups. The results of these studies should be interpreted with caution, as changes over time could be due to the passage of time. To date, DTT has been formally investigated in AD,^{20,25–26} PD,^{21,23–24, 27–32} and brain injury.^{22,33} Many of these studies provide weak evidence due to lack of blinding and small sample sizes. Studies that did not present raw data were excluded from Figure 2, further challenging generalization of these results.

CONCLUSIONS

Although motor-cognitive interference has been well described in many neurologic populations, training studies that met the inclusion criteria were limited to PD, AD and brain injury. Furthermore, limitations in the reviewed studies make generalizing results of this review into evidence-based recommendations difficult. While DTT appears to be safe and effective for improving spatiotemporal measures of DT gait in individuals with PD, AD and brain injury, more research is needed to define the specific DT interventions that are most effective and to better assess whether some interventions are more appropriate than others for a specific diagnostic group.

In conclusion, this first review to examine the outcomes of DTT across neurologic disorders suggests that DTT may improve spatiotemporal measures (velocity, step length) of single-task gait in PD and AD and DT gait in PD, AD, and brain injury, and may have a modest impact on balance and cognition in PD and AD. Future studies including larger sample sizes and greater standardization of DT protocols (e.g., intensity, frequency and duration) and outcome measures would greatly assist in the determination of the efficacy of such interventions in neurologic populations. Improvement of DT ability in individuals with neurologic disorders holds potential for improving gait, balance and cognition that may impact independence and fall risk.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Search strategy flowchart

Figure 2.

Treatment effects for dual-task (DT) training versus comparison treatments for all trials with full data sets. Treatment effects favoring DT training assigned positive Hedges standardized mean difference (SMD) values. Mean changes were used in the case of repeated measures data and mean differences were used for clinical trials data.

Berg Balance Scale (BBS); Dual-task cost (DTC); dual-task (DT); Frontal Assessment Battery (FAB); single-task (ST).

Table 1

Trial Ratings on the Clinical Relevance Scale³⁵

Trial	Clinical Relevance Score				
	1	2	3	4	5
Evans et al. ²²	1	1	1	1	1
Yogev- Seligmann et al. ²⁸	1	1	1	1	1
Yen et al. ²¹	1	1	1	0	1
Fok et al. ²³	1	1	1	0	1
Fok et al. ²⁴	1	1	1	0	1
deAndrade et al. ²⁵	1	1	1	0	1
Brauer and Morris ²⁹	1	1	1	0	1
Canning et al. ³⁰	1	1	1	0	1
Schwenk et al. ²⁰	1	0	1	0	1
Coelho et al. ²⁶	1	0	1	0	1
dos Santos Mendes et al. ²⁷	1	1	0	0	1
Rochester et al. ³¹	1	0	1	0	1
Mirelman et al. ³²	1	0	1	0	1
Sveistrup et al. ³³	0	0	0	0	0

All scores are coded 1=yes; 0=no for the following Clinical Relevance Scale items: 1. Are the patients described in detail so that you can decide whether they are comparable to those you see in practice? 2. Are the interventions and treatment settings described well enough so that you can provide the same for your patients? 3. Were all clinically relevant outcomes measured and reported? 4. Is the size of the effect clinically important? 5. Are the likely treatment benefits worth the potential harms?

Table 2

Characteristics of Included Studies

Study/Year	Design	Participant Characteristics, Inclusion Criteria	Interventions	Comparison Interventions	Outcome Measures
Evans et al. (2009) ²²	Non-Blinded RCT	Dx: Acquired Brain Injury (control) 5 TBI, 4 CVA; (experimental) 7 TBI, 2 CVA, 1 Tumor Age: (control) 45.11±9.73; (experimental) 44.4±8.51 Gender: (control) 1F, 8M; (experimental) 1F, 9M Inclusion Criteria: 18–65 years old; diagnosis of brain injury or other neurologic illness; evidence of performance at least 1 SD below the mean on the Divided Attention & Dual-Tasking test battery; self-reported difficulties with dual-tasking in everyday life	N= 10 30 minute sessions, 1x/week for 5 weeks with a therapist and at-home practice 2 practice sessions/day, 5 days/week for 5 weeks. Walking while: a. Listening to instrumental music b. Listening to vocal music c. Listening to a recording of talk-based radio and then answering recorded questions d. Verbal fluency task e. Answer autobiographical questions Walking around 2–3 obstacles was introduced with these tasks as they became easier.	N= 9 Null Control with ~5–10 minute weekly phone calls from a research therapist to review general progress, enquire about difficulties or successes in dual-task situations. Subjects also recorded examples of dual-task difficulties in a diary to simulate awareness-raising that training may have produced.	Walking + clicking a mechanical counter (motor-motor dual-task) Walking + Sentence verification task (motor-cognitive dual-task) Walking + Tone Counting (motor-cognitive task) Memory Span & Tracking Task TEA Telephone Search while Counting Dual Tasking Questionnaire
Yogev-Seligmann et al. (2012) ²⁸	Test-Retest (Repeated Measures)	Dx: Parkinson's disease Age: 63.8 ±8.4 Gender: 0F, 7M Inclusion Criteria: idiopathic PD; Hoehn & Yahr Stage II-III; taking anti-parkinsonian medications; independent ambulators; lack of dementia; between 50–90 years old.	N=7 25 minutes/session, 3x/week for 4 weeks In each training session: 5 blocks of 5 minutes of walking with three types of cognitive tasks per 5-minute block, all delivered through earphones. Instructions were delivered with variable prioritization for the motor vs. cognitive tasks. Knowledge of results feedback was given for fluency and arithmetic tasks; knowledge of performance feedback was given for gait performance.	No control group	Evaluated pre and post-training and 1 month following training Timed Up and Go UPDRS motor scale Single task walking Dual task walking with: a) Verbal fluency, b) Serial 3 subtractions, c) an information processing task, and d) An additional task not included in the training
Yen et al. (2011) ²¹	Single-Blinded RCT	Dx: Idiopathic PD Age: (control) 71.6±5.8; (conventional balance) 70.1±6.9; (virtual reality) 70.4±6.5 Gender: (control) 5F, 9M; (conventional balance) 2F, 12M; (virtual reality) 2F, 12M Inclusion Criteria: diagnosis of idiopathic PD	Training provided 30 minutes per session, 2x/week for 6 weeks N=14 Virtual Reality Group: 10 minutes of stretching exercises to warm-up followed by 20 minutes of standing on the VR balance board and moving their weight with an ankle strategy to navigate a virtual environment N= 14	N=14 Null Control	Sensory Organization Test (SOT) (conditions 1 through 6) to assess center of pressure and center of gravity sway Verbal reaction time during a dual-task while standing= each of the 6 conditions of the SOT + auditory arithmetic subtraction task

Study/Year	Design	Participant Characteristics, Inclusion Criteria	Interventions	Comparison Interventions	Outcome Measures
Fok et al. (2010) ²³	Test-Retest (Repeated Measures)	Dx: Parkinson's disease Age: (control) 57.7±12.3; (experimental) 66.8±9.0 Gender: not reported Inclusion Criteria: Diagnosis of idiopathic PD; subjective walking difficulties; able to independently ambulate 12m × 25 reps; MMSE 24.	N=6 A single training session lasting 30 minutes. Participants were given verbal cues to achieve longer stride lengths during comfortable walking and then were coached on a walking with a subtraction task (serial 3 subtraction)	N=6 Null Control; 30 minutes of sitting and reading a magazine	GAITrite electronic walkway was used to measure Gait Speed and Stride Length during single-task walking and dual-task walking (walking with serial 3 subtraction)
Fok et al. (2012) ²⁴	Test-Retest (Repeated Measures)	Dx: Parkinson's disease Age: (control) 73.0±12.0; (experimental) 66.3±11.7 Gender: not reported Inclusion Criteria: Diagnosis of idiopathic PD; subjective walking difficulties; able to independently ambulate 12m × 25 reps; MMSE 24	N=6 A single training session lasting 30 minutes. Participants were given verbal cues to achieve longer stride lengths during comfortable walking and then were coached on a walking with a subtraction task (serial 3 subtraction)	N=6 Null Control; 30 minutes of sitting and reading a magazine	GAITrite electronic walkway was used to measure Gait Speed and Stride Length during single-task walking and dual-task walking (walking with serial 3 subtraction)
de Andrade et al. (2013) ²⁵	Test-Retest (Repeated Measures)	Dx: Alzheimer's disease Age: (control) 77.0±6.3; (experimental) 78.6±7.1 Gender: (control) 12F; 4M; (experimental) 12F; 2M Inclusion Criteria: Diagnosis of mild to moderate dementia on the Clinical Dementia Rating, ability to walk independently, and 70% minimum attendance rate at exercise sessions, lack of musculoskeletal or cardiovascular impairments that precluded exercise	N=14 1 hour sessions, 3x/week for 16 weeks Multimodal Exercise Intervention: 5 minute warm-up, 20 minutes of aerobic work, 35 minutes of dual-task activities. Dual-task activities included weight training, agility, flexibility and balance training with concurrent cognitive tasks of attention, language and executive attention; (e.g., exercising with weights while counting backwards) Complexity of both motor and cognitive tasks was increased every 4 weeks.	N=16 Null Control	Frontal Assessment Battery, Clock Drawing Test, Wechsler Adult Intelligence Scale, Geriatric Depression Scale, MMSE, Montreal Cognitive Assessment, Modified Baecke Questionnaire for the Elderly Force Platform: AP and ML-COP four conditions: a) Looking at a target with arms at sides; b) Looking at a target while counting backward from 30; c) Looking at the target and holding a tray; d) Looking at the target, holding a tray, and counting backward from 30. Berg Balance Scale, Timed Up and Go, 30-second sit-to-stand test, sit-and-reach test.
Brauer and Morris (2010) ²⁹	Test-Retest	Dx: Parkinson's disease Age: 68.5±11.3 Gender: 8F; 12M	N=20 20 minutes of dual-task training focusing on improving step length during working	No control group	10m walking trials on the GAITrite under seven conditions:

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Study/Year	Design	Participant Characteristics, Inclusion Criteria	Interventions	Comparison Interventions	Outcome Measures
Coelho et al. (2013) ²⁶	Test-Retest (Repeated Measures)	Inclusion Criteria: MMSE (17-30) ≥ 24; Age: (control) 77.1±7.4; (experimental) 78.0±7.3; Gender: not reported Inclusion Criteria: Diagnosis of Alzheimer's disease, lack of vertigo syndrome, extrapyramidal symptoms, other limitations to gait, and neuropsychiatric conditions	N=14 1 hour sessions, 3x/week for 16 weeks Multimodal Exercise Intervention: strength/resistance training, aerobic capacity, flexibility, balance and agility exercise with concurrent cognitive activities requiring focused attention, planned organization of answers, abstraction, motor sequencing, judgment, self-control behavior, and mental flexibility: (e.g., bouncing a ball while generating words (such as animal names)). Complexity of tasks was increased throughout the intervention.	N=13 Null Control	Frontal Assessment Battery, Clock Drawing Test, Wechsler Adult Intelligence Scale-III, Geriatric Depression Scale Kinematic parameters of gait (2D kinematics) (stride length, stride time, cadence) during single and dual-task walking
dos Santos Mendes et al. (2012) ²⁷	Test-Retest (Repeated Measures)	Dx: Parkinson's disease Age: (control) 68.7±4.1 (experimental) 68.6±8.0 Gender: not reported Inclusion Criteria: idiopathic PD; Hoehn & Yahr I and II; receiving levodopa treatment; MMSE ≥ 24; a score of 5 on the Geriatric Depression Scale; no prior experience with Wii-Fit	N=16 2x/week for 14 weeks Individualized training sessions including 30 minutes of global mobility exercises followed by training on the Wii Fit, using 10 games that challenged balance, marching, quick stopping, and paired upper and lower extremity movements.	N=11 healthy elderly Controls completed the same training as the experimental group.	Evaluated pre and post-training and at a 60 day follow up: Functional Reach Test Game play performance was recorded to monitor inter-session learning curve and retention at follow-up.
Rochester et al. (2010) ³¹	Test-Retest (Repeated Measures)	Dx: Parkinson's disease Age: 76.4±12.9 Gender: 3F, 16M Inclusion Criteria: idiopathic PD; Hoehn & Yahr Stage I-IV; no other medical issues affecting mobility	N=19 (included in analysis) Nine 30-minute sessions of cueing therapy for gait impairments over 3 weeks in their home environment Cueing therapy included walking in time to a metronome during functional motor-motor and motor-cognitive dual-tasks	No control group	Gait (via video recording) to assess velocity, step amplitude, and step frequency UPDRS Balance: tandem stance time over 3 trials
Mirelman et al. (2011) ³²	Test-Retest (Repeated Measures)	Dx: Parkinson's disease Age: (experimental) 67.1±6.5 Gender: (experimental) 6F, 14M Inclusion Criteria: idiopathic PD; Hoehn & Yahr Stage II-III; walking difficulties identified by	N=20 3 sessions/week for 6 weeks Virtual Reality program requiring participants to process multiple stimuli simultaneously and make decisions about obstacle negotiation in two planes while continuing to walk on a treadmill.	Historical active control group of patients with PD who followed a similar program of treadmill training, but without VR.	Stride Length, gait variability, DTC, and obstacle clearance on the GAITrite and accelerometer during three conditions: a. Comfortable pace b. Walk with serial 3 subtraction

Study/Year	Design	Participant Characteristics, Inclusion Criteria	Interventions	Comparison Interventions	Outcome Measures
Sveistrup et al. (2003) ³³	Test-Retest	Dx: Moderate or Severe Traumatic Brain Injury Age: not reported Gender: not reported Inclusion Criteria: Diagnosis of moderate to severe TBI sustained at least 6 months earlier; no current participation in acute inpatient rehabilitation; able to stand independently for two minutes	1 hour sessions, 3x/week for 6 weeks N=5 Conventional Exercise Group: Balance exercises focusing on stepping, picking up objects, single and double limb stance, moving within the base of support, walking, sit-to-stand, reaching, hopping, jumping, and jogging. N=4 VR Exercise Group: requires participants to reach, move within base of support, step, sit-to-stand, hop, jump and jog	N=5 Null Control	c. Walk while negotiating two obstacles (box and line) 6 Minute Walk Test UPDRS motor subscale 4 Square Step Test PD quality of life questionnaire Trail Making Test Measures of quiet stance and gait speed Activities Balance Confidence Scale Community Balance & Mobility Scale

Anterior-posterior Center of Pressure (AP-COP); Cerebrovascular Accident or Stroke (CVA); Diagnosis (Dx); Dual Task Cost (DTC); Female (F); Male (M); Medial-lateral Center of Pressure (ML-COP); Mini-Mental State Examination (MMSE); Parkinson's disease (PD); Sensory Organization Test (SOT); Test of Everyday Attention (TEA); Traumatic Brain Injury (TBI); United Parkinson's Disease Rating Scale (UPDRS); Virtual Reality (VR).