1-1-2021

The Effect of Dual-Task Testing on Balance and Gait Performance in Adults with Type 1 or Type 2 Diabetes Mellitus: A Systematic Review

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Citation of this paper:
Omana, Humberto; Madou, Edward; Montero-Odasso, Manuel; Payne, Michael; Viana, Ricardo; and Hunter, Susan W., "The Effect of Dual-Task Testing on Balance and Gait Performance in Adults with Type 1 or Type 2 Diabetes Mellitus: A Systematic Review" (2021). *Physical Therapy Publications*. 83.
https://ir.lib.uwo.ca/ptpub/83

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Running Title: Dual-task balance and gait in adults with diabetes

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ABSTRACT

Background: Individuals with diabetes mellitus (DM) are susceptible to balance, gait and cognitive impairments. Importantly, diabetes affects executive function, a set of cognitive processes critical to everyday cortical function and mobility. Reduced executive function is a risk factor for falls in people with DM. Dual-task testing, the completion of two tasks at once, enables the examination of the cognitive-mobility relationship. A synthesis of the literature on the effects of dual-task testing on the balance and gait of individuals with DM has not been performed.

Objective: To systematically review the literature on the effect of dual-task testing on balance and gait in people with DM.

Methods: Databases EMBASE, CINAHL, MEDLINE, PsycINFO, Scopus and Web of Science were searched (inception-April 2020). Inclusion criteria: participants were adults with a diagnosis of DM, instrumented dual-task balance and/or gait was assessed, and articles were published in English.

Results: Ten articles met inclusion criteria- three examined dual-task balance and seven dual-task gait. In people with DM with or without peripheral neuropathy, dual-task resulted in larger sway velocities during standing tests. Individuals with DM and peripheral neuropathy had impaired dual-task gait; specifically, and more consistently, reduced pace and rhythm compared to controls or people with DM without peripheral neuropathy.

Conclusion: The findings support a compromise in the cognitive-mobility relationship of people with DM, and especially in those with peripheral neuropathy. Future research should continue to examine the cognitive-mobility relationship in order to understand the increased prevalence of falls in this population.

Keywords: Multitasking Behavior, Postural Balance, Gait, Diabetes Mellitus, Aging, Systematic Review.

1. INTRODUCTION

An estimated 422 million people around the world are currently living with either type 1 or type 2 diabetes mellitus (DM).[1] The global prevalence of DM has almost doubled from 4.7% in 1980 to 8.5% in 2016[1] and is expected to rise to 10.4% by the year 2040[2]. An aging population, physical inactivity and increased obesity rates are credited as driving factors for the rapid growth of diabetes.[3] Acute and prolonged periods of dysregulated blood glucose in people with type 1 or type 2 DM results in systemic micro-and macrovascular damage that is associated with increased morbidity, especially in the area of mobility dysfunction.[4, 5]

Chronic diabetes-related vascular damage places people with type 1 or type 2 DM at a risk of developing a myriad of complications.[4] In general, 20% to 50% of people with DM are diagnosed with peripheral neuropathy (PN) during their lifetime, which negatively affects sensory and/or motor nerve fibers.[6–11] Additionally, altered function in somatosensory, muscular, visual and vestibular function is common and can result in balance and gait impairments.[5] Deterioration in one or more of these systems places individuals at an increased risk for falls.[12, 13] Irrespective of diabetes type, and compared to healthy community-dwelling older adults, older adults with diabetes have a 64% increase in the risk for falls,[14] and 35% report having at least one fall annually[15].

Another important factor in mobility dysfunction among people with type 1 or type 2 DM is cerebral vascular damage that can result in mild to moderate cognitive impairment.[16] Insulin resistance, increased oxidative stress, and the accumulation of plaques and microvascular lesions within brain tissue may explain the cognitive impairment observed in people with DM.[17, 18] Neurobehavioral studies show that people with either type 1 or type 2 DM often develop impaired speed of processing, attention, memory and executive function.[19, 20] Executive function is an umbrella term encompassing various higher-order cognitive processes associated with the reasoning, planning, monitoring and adjustments that are involved in everyday mobility.[21] Importantly, executive function is critical for the sensory integration used to coordinate balance and gait motor output.[22] Elucidated in people with type 2 DM, an inter-relationship exists between declines in balance, gait and executive function and an elevated risk for falls.[23, 24]

The inter-relationship between cognition and mobility can be examined through dual-task testing, the completion of a balance or gait task concurrently with a secondary task.[25] Dual-task testing is considered a capacity test that exploits the fact that cognitive resources are limited.[26] Under dual-tasking, if the cognitive demands associated with the tasks exceeds an individual's cognitive capacity then performance of one or both tasks declines.[22] The relative change in motor or cognitive performance between single- and dual-task trials is termed the task cost. Dual-task testing has been demonstrated in other patient populations with cognitive impairment to reveal subtle pathology-specific changes that impact balance and gait.[27, 28]

Considering the changes in cognitive function that have been identified in people with either type 1 or 2 DM, dual-task testing may provide a functional biomarker for mobility impairment and risk for falls. Unfortunately, a synthesis of the current literature on the effects of dual-task testing on the mobility of people with DM does not currently exist yet is warranted to clearly provide an overview of the existing literature. Therefore, the goals of this study were: (1) to systematically review the effects of dual-task testing on instrumented recordings of balance and gait in people with type 1 or type 2 DM, (2) to examine if dual-task effects were selectively different in people with DM compared to healthy adults, and (3) to determine if dual-tasking effects were dependent on the secondary task used or the presence of PN.

2. MATERIALS AND METHODS

2.1. Literature Search Strategy

The electronic databases EMBASE, CINAHL, MEDLINE, PsycINFO, Scopus and Web of Science were searched for published scientific articles (inception – April 23, 2020) in duplicate by authors H.O and E.M using a standardized search strategy generated in consultation with a research librarian. (Supplementary Table 1). No filtering or restrictions were applied to the database search strategy. The systematic review was designed to adhere to The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[29] and was registered in The International Prospective Register of Systematic Reviews (PROSPERO; #CRD42019146722).

2.2. Inclusion and Exclusion Criteria

Scientific articles meeting the following criteria were included: (1) participants were diagnosed with diabetes mellitus (type 1 or 2), (2) were 18 years or older, (3) dual-task performance of balance or gait was paired with a secondary cognitive or motor task, and (4) balance or gait was assessed using instrumented technology (e.g., accelerometers, electronic walkways, cameras, force plates, etc.). Studies were excluded if: (1) not published in English, (2) they were literature reviews, scoping reviews, narrative reviews, or grey literature (e.g., conference papers, theses, etc.), (3) contained no single-task or dual-task balance or gait tests, (4) provided indirect measures of balance or gait (e.g., gait velocity was calculated using distance and stopwatch timed trials), (5) unable to extract data, (6) did not include a comparison group who were either controls (CN), people without a diagnosis of diabetes, or people with DM without a diagnosis of PN, (7) participants resided in a nursing home or hospital at the time of recruitment, or (8) participants were diagnosed with a separate disease affecting mobility and/or cognition (e.g., Parkinson's disease, Alzheimer's disease, etc.). None of the studies gathered were excluded based on quality of reporting or study design.

2.3. Article Selection

All abstracts and titles from articles identified through the database search strategy were independently reviewed by two authors (H.O, E.M) for the inclusion criteria after the removal of duplicates. Each article identified in the first step as eligible for inclusion then underwent an independent full-text review by each reviewer. A consensus was required for articles to be included in the final analysis. Any disagreement regarding the inclusion of an article was brought to a third reviewer (S.H) for resolution. References of the final selected articles and relevant literature reviews were hand searched for additional articles not captured by the initial electronic search strategy.

2.4. Data Extraction and Examination

A standardized data extraction sheet was used to collect relevant information from each article included in the systematic review. The following details were extracted by two authors (H.O, E.M) in duplicate: lead author and year of publication, country of origin, study design, recording instrument used, mean age (years) and standard deviation, body mass index (BMI), sample size (total and per group) and percentage of females, type of diabetes in participant group, presence of neuropathy, characteristics of comparison group, details of the balance or gait task and secondary task used, mean and standard deviations of single-task and dual-task trials, and main results reported. For intervention studies, only baseline outcome measures were extracted. For articles in which data was unable to be extracted, the corresponding author of the manuscript was contacted by one reviewer (H.O) a total of two times.

To aid the understanding of how studies have assessed the effect of dual-task testing on the balance and gait of people with DM, information related to the secondary task used, and the balance and gait parameters reported were categorized using different schemas. Secondary task classification followed the schema defined by Al-Yahya et al.[30] which includes: (1) reaction time tasks, (2) discrimination and decision-making tasks, (3) mental tracking tasks, (4) working memory tasks, (5) verbal fluency tasks, and (6) an "other" group for studies that have used a secondary task not fitting any one classification. A reaction time task assesses processing speed from a sensory stimulus to a selected behaviour (e.g., button press); a discrimination and decision-making task requires the participant to respond only to a specific feature of the stimulus (e.g., Stroop test); a mental tracking task involves holding and manipulating information prior to a response (e.g., number subtractions); a working memory task involves the recall of stored information (e.g., grocery list recall); and a verbal fluency task involves the production of words under certain conditions (e.g., names of animals starting with a specific letter).[30] Moreover, an extensive number of center-of-pressure balance[31] and spatial-temporal gait parameters[32] are currently used in research. Static balance equilibrium involves the maintenance of the center-of-mass within the base of support, which is reflected upon the center-of-pressure or the resultant ground reaction force.[33] The trajectory of the center-of-pressure can be recorded using a force-measuring platform, such as a force plate. For the purposes of this systematic review, center-of-pressure variables assessing balance control were categorized into: (1) distance, (2) area, or (3) velocity. Distance refers to the total center-of-pressure displacement; area represents the radius encompassing the center-of-pressure trajectory; and velocity refers to the total center-of-pressure distance over time.[31] Extracted spatial-temporal gait parameters were categorized using the model developed by Lord et al.[34] which includes five domains: (1) pace, (2) rhythm, (3) variability, (4) asymmetry, and (5) postural control. Pace refers to gait velocity and stride/step length; rhythm refers to the cadence of gait; gait variability is a reflection of gait consistency; asymmetry refers to left and right body hemisphere equality; and postural control refers to the base of support gait stability.[32, 34, 35]

2.5. Methodological Reporting Quality Assessment

The Downs and Black (1998) tool was used to assess the reporting quality of each manuscript included in the final analysis.[36] Studies are assessed for: (1) reporting, (2) internal validity (bias), (3) internal validity (confounding), and (4) external validity. The Downs and Black tool is recommended for its high internal consistency and test-retest reliability, good inter-rater reliability, face and content, and criterion validity.[36, 37] Total scores for the Downs and Black tool range from 0 to 32 with a higher score indicating a more complete reporting of items. The Downs and Black tool was completed independently by two reviewers (H.O, E.M) for each article. Consensus on all items was required.

2.6. Data Analysis

An *a priori* aggregate data meta-analysis was planned, whereby pooled estimates of the dual-task effect difference for each balance and gait domain was to be performed between people with DM and healthy adults, or between people with DM and people with DM and PN, separately. However, due to limited overlap of participant characteristics, study designs, methodologies, outcome measures and the inability to extract important information from 30% (n=3) of included manuscripts, a meta-analysis was deemed not appropriate and a qualitative synthesis of the studies was performed instead.

3. RESULTS

Of 4,346 articles that were identified from the database searches, 65 underwent full-text review and a total of 10 articles met criteria for inclusion in the systematic review. (Figure 1). Three articles examined the effect of dual-task testing on balance[38–40] and the remaining seven investigated dual-task gait[41–47]. (Table 1). Most articles were excluded at the full-text review stage because they either did not use instrumented technology to record balance or gait parameters (n=29) or dual-task testing was not part of their protocol (n=26). (Supplementary Table 2).

Table **1**, Characteristics of articles included in the systematic review.

Author	**Study design**	**Instrument**	**Mean age (age range) (years)**	**Mean BMI (kg/m^2)**	**Sample size (% female)**	**Type of diabetes**	**Presence of neuropathy**	**Comparison group characteristics**
Dual-task balance								
Gorniak et al. 2019[38] (USA)	Cross-sectional	Force plate (NeuroCom)	DM: 60.3 ± 6.2 (50-72) CN: 60.0 ± 7.0 (NR)	NR	DM: 10 (60.0) CN: 10 (NR)	T2D: All	Mixed	Age-and sex-matched
Hijmans et al. 2008[39] (Netherlands)	Cross-sectional	Force plate (Bertec 4060)	DM(PN): 52.1 ± 6.0 (NR) CN: 51.8 ± 5.6 (NR)	NR	DM(PN): 17 (52.9) CN: 15 (53.3)	T1D: 11 (64.7) T2D: 6 (35.3)	By group	Age-and sex-matched
Smith et al. 2014[40] (England)	Cross-sectional	Posturography (CDR system)	DM: 70.9 ± 5.0 (NR) CN: 69.8 ± 6.8 (NR)	DM: 30.2 ± 4.5 CN: 26.8 ± 3.6	DM: 36 (58.3) CN: 36 (41.7)	T2D: All	NR	Age-matched
Dual-task gait								
de Bruin et al. 2012[41] (Switzerland)	Cross-sectional	Triaxial accelerometer (DynaPort Mini-Mod), lower back	DM: 60.3 ± 3.4 (55-67) DM(MPN): 63.0 ± 6.1 (50-70) DM(SPN): 62.8 ± 6.3 (53-70)	DM: 29.2 ± 2.9 DM(MPN): 25.6 ± 3.4 DM(SPN): 30.2 ± 0.7	DM: 12 (16.7) DM(MPN): 11 (27.3) DM(SPN): 6 (16.7)	T2D: All	By group	NR
El-Tamawy et al. 2016[42] (Egypt)	Cross-sectional	Video Motion Analysis	DM(MoPN): NR (40-60) DM: NR (40-60)	Range: 20-30	DM(MoPN): 20 (45.0) DM: 20 (35.0)	T2D: All	By group	Age-and sex-matched
Hewston et al. 2018[43] (Canada)	Cross-sectional	Video Motion Analysis (Optotrak 3020), 6.0 m	DM: 70.5 ± 5.1 (NR) CN: 72.0 ± 5.5 (NR)	DM: 6 had a BMI > 30 CN: 2 had a BMI > 30	DM: 12 (41.7) CN: 12 (41.7)	NR	No	Age-and sex-matched
Holtzer et al. 2018[44] (USA)	Cross-sectional	Electronic walkway (Zeno™), 1.2 x 4.3 m	DM: 77.7 ± 6.8 (NR) CN: 76.7 ± 6.7 (NR)	DM: 31.90 ± 6.9 CN: 28.82 ± 6.4	DM: 43 (13.7) CN: 272 (58.5)	T2D: All	Mixed	NR

Kang et al. 2020[47] (USA)	Cross-sectional	Two Triaxial accelerometers (LegSys™), x2 anterior middle femur, x2 anterior distal tibia, x1 lower back	DM(SPN): 72.6 ± 5.6 (NR) CN: 77.9 ± 8.2 (NR)	DM(SPN): 31.63 ± 6.07 CN: 27.05 ± 4.23	DM(SPN): 38 (47.4) CN: 33 (60.6)	T2D: All	By group	NR
Paul et al. 2009[45] (Scotland)	Cross-sectional	Electronic walkway (GAITRite™), 0.6 x 3.7 m	DM(SPN): 69.0 ± 3.0 (NR) DM: 70.0 ± 2.9 (NR)	NR	DM(SPN): 15 (26.7) DM: 15 (53.3)	NR	By group	NR
Roman de Mettelinge et al. 2013[46] (Belgium)	Cross-sectional	Electronic walkway (GAITRite™), 0.89 x 8.3 m	DM(PN): 74.1 ± 8.2 (NR) DM: 74.8 ± 7.5 (NR) CN: 71.3 ± 8.1 (NR)	DM(PN): 31.3 ± 6.3 DM: 30.6 ± 6.9 CN: 27.6 ± 4.3	DM(PN): 28 (64.3) DM: 28 (46.4) CN: 45 (55.6)	T2D: All	By group	Age-and sex-matched

Footnote:

CDR: Cognitive Drug Research cognitive assessment system; CN: control; DM: people with diabetes mellitus; MPN: mild neuropathy; MoPN: moderate neuropathy; NR: not reported; PN: neuropathy; SPN; severe neuropathy; T1D: type 1 diabetes; T2D: type 2 diabetes.

3.1. The Effect of Dual-Task Testing on Balance in People with Diabetes

3.1.1. Study Participants:

A total of three studies examined the effect of dual-task testing on balance control.[38–40] (Table 1). The total sample across studies was 124 (DM: 46; DM(PN): 17, CN: 61) with sample sizes ranging from 20 to 72 participants. Two studies recruited people with type 2 diabetes[38, 40] and one recruited both people with type 1 and type 2 DM[39]. The time since a DM diagnosis was reported by two studies, and ranged from 9.6 ± 7.0 to 10.1 ± 6.75 years.[38, 40] Smith et al.[40] was the only study to specify that 61.1% of participants within their DM group were either taking metformin or insulin as part of their regular treatment. Both Gorniak et al.[38] and Smith et al.[40] additionally reported on BMI or glycated haemoglobin levels. All three studies excluded participants based on the presence of comorbidities that may affect balance control, such as neurological disorders, severe visual impairment, or ulcer/amputations.[38–40]

Two of the three studies stated that a diagnosis of DM was confirmed using medical records,[38, 39] while one study only reported that participants were recruited from a local DM network yet assessed glycated haemoglobin levels to confirm grouping.[38–40] Importantly, no one study specified what clinical guideline was used to diagnose DM in the first place. The presence of PN was reported in two studies,[38, 39] where the diagnosis was determined through a clinical assessment or electrodiagnosis,[38] or extracted from medical charts[39]. Importantly, none of the studies provided details as to the diagnosis methodology, or the type, cause, distribution, severity or treatment status of PN. The average age (years) of participants across studies ranged from 60.3 to 70.9 for people with DM, 51.8 to 69.8 for CN and was 52.1 for a sample of people with DM and PN. Studies included age-matched[40] or age-and sex-matched older adult controls[38, 39]. Executive function, examined using the Montreal Cognitive Assessment and the Trail Making Test part A and B, was found to be statistically different and worse in people with DM compared to the CN group in two studies.[38, 40]

3.1.2. Balance Parameters:

Only one study recorded balance parameters covering all three balance domains (sway distance, area, and velocity).[38] (Table 2). The most examined balance domains were center-of-pressure (COP) area and anterior-posterior (AP) and medio-lateral (ML) sway velocity.

3.1.3. Balance and Dual-Task Testing Methods:

All studies examined static balance control in standing.[38–40] Balance parameters were recorded using force plates[38, 39] or a computerized sway meter device[40]. Only two studies reported on the feet placement of participants: Gorniak et al.[38] outlined feet placement as to allow for within subject consistency, while Hijmans et al.[39] standardized feet placement between participants (5 cm distance between heels at 15° external rotation). No study examined balance control under more challenging positions, such as semi-tandem, tandem or single leg standing.

The secondary tasks involved either mental tracking or working memory. Mental tracking was number subtractions[39, 40], while working memory was an “n-back” word response secondary task[38]. For two studies, different levels of difficulty for the secondary tasks were examined.[38, 40] Only one study reported on the instructions given to participants regarding task prioritization, which were to not to prioritize any one task.[38]

3.1.4. Dual-Task Testing on Sway Distance:

One study examined the effect of dual-task testing on sway distance and reported AP and ML sway length (m).[38] Compared to CN, people with DM had significantly greater single-task AP and ML sway distances. Dual-task testing did not result in changes in sway length for either group. Dual-task effects between groups were not statistically different.

3.1.5. Dual-Task Testing on Sway Area:

Two studies examined the effect of dual-task testing on sway area.[38, 40] During single-task, total COP area (cm^2), mean sway area (1/3 degrees of angle of arc), and minimum time to boundary (ms) were significantly higher in people with DM compared to CN. Dual-task testing resulted in greater sway area, yet found it not to be significantly different from single-task trials for any group. No significantly different dual-task effects were observed between groups. Interestingly, Smith et al.[40] reported that a statistical difference dual-task performance between groups was only observed in the trials of balance paired with arithmetic subtractions by threes but not sevens upon adjusting for body mass index and depression status.

3.1.6. Dual-Task Testing on Sway Velocity:

Two studies examined the effect of dual-task testing on sway velocity and reported on mean COP displacement (m or mm/s) and/or root-mean-square velocity (mm/s) in both the AP and ML directions.[38, 39] For single-task, significantly higher AP and ML sway velocities were observed in people with DM with or without PN compared to CN. Dual-task testing resulted in significantly higher AP and ML sway velocities in people with DM.

3.1.7. Dual-Task Testing on Secondary Task Performance:

Secondary task performance was reported by one study.[38] Individuals with DM had statistically lower accuracy throughout dual-task testing (an “n-back” word task) compared to CN.

Table **2**, Summary of results of the effect of dual-task testing on balance control of people with diabetes.

Author	**Balance Task and Secondary Task**	**Balance Domains**			**Main Results**
		Distance	**Area**	**Velocity**	
Gorniak et al. 2019[38](*)	. **Balance Task:** Upright stance with arms crossed across chest, EO. Relaxed standing position. Standardized across trials. **Secondary Task (Working memory):** Recall of “nth” word from a random list. Instructed to not prioritize any one task. DT Levels: 0, 1, or 2 “nth” word recall. Block randomized.	AP path length (m): (ST) DM: NR CN: NR (DT- Level 0) DM: NR CN: NR (DT- Level 1) DM: NR CN: NR (DT- Level 2) DM: NR CN: NR ML path length (m): (ST) DM: NR CN: NR (DT- Level 0) DM: NR CN: NR (DT- Level 1) DM: NR CN: NR (DT- Level 2) DM: NR CN: NR	COP area (cm^2): (ST) DM: NR CN: NR (DT- Level 0) DM: NR CN: NR (DT- Level 1) DM: NR CN: NR (DT- Level 2) DM: NR CN: NR AP TTB (ms): (ST) DM: NR CN: NR (DT- Level 0) DM: NR CN: NR (DT- Level 1) DM: NR CN: NR (DT- Level 2) DM: NR CN: NR ML TTB (ms): (ST) DM: NR CN: NR (DT- Level 0) DM: NR CN: NR	AP velocity (m/s): (ST) DM: NR CN: NR (DT- Level 0) DM: NR CN: NR (DT- Level 1) DM: NR CN: NR (DT- Level 2) DM: NR CN: NR	**Balance Task (ST):** Group differences existed across all variables, whereby people with DM had higher values: AP path length ($p<0.001$), ML path length ($p<0.001$), COP area ($p<0.001$), AP TTB ($p<0.005$), and ML TTB ($p<0.05$). **Balance Task (DT):** Dual-task effect found only for AP velocity ($p<0.05$), which increased with task difficulty. **Secondary Task:** Performance was different between groups across conditions ($p<0.01$). Individuals with DM were found to make more errors, which increased with task difficulty.

			(DT- Level 1) DM: NR CN: NR (DT- Level 2) DM: NR CN: NR		
Hijmans et al. 2008[39](*)	**Balance Task:** Standing with heels 5 cm apart and externally rotated at 15°. Unknown arm placement. Standing task completed for both EO and EC. **Secondary Task (Mental tracking):** Continuously subtracting six from a random number. No instructions on prioritization of tasks.			AP RMS (EO) velocity (mm/s): (ST) DM(PN): 10.0 ± 0.6 CN: 7.5 ± 0.5 (DT) DM(PN): 17.1 ± 1.7 CN: 10.7 ± 0.7 AP RMS (EC) velocity (mm/s): (ST) DM(PN): 16.9 ± 2.7 CN: 9.6 ± 0.9 (DT) DM(PN): 24.3 ± 3.3 CN: 12.6 ± 1.1 ML RMS (EO) velocity (mm/s): (ST) DM(PN): NR CN: NR (DT) DM(PN): NR CN: NR ML RMS (EC) velocity (mm/s): (ST) DM(PN): NR CN: NR (DT)	**Balance Task (ST):** NR. **Balance Task (DT):** Dual-task effect observed for mean velocity of COP displacement ($p<0.01$), AP COP RMS ($p=0.01$), ML RMS COP ($p<0.01$). **Secondary Task:** NR.

				DM(PN): 14.9 ± 1.2 CN: 9.9 ± 0.8 Mean velocity of COP displacement (EO) (mm/s): (ST) DM(PN): 11.62 ± 0.75 CN: 9.38 ± 0.60 (DT) DM(PN): 17.83 ± 0.75 CN: 11.33 ± 0.65 Mean velocity of COP displacement (EC) (mm/s): (ST) DM(PN): 17.93 ± 0.75 CN: 12.23 ± 0.75 (DT) DM(PN): 24.29 ± 0.70 CN: 13.83 ± 0.60	
Smith et al. 2014[40](*)	**Balance Task:** Standing upright, EO. **Secondary Task (Mental tracking):** Continuously subtracting “nth” from a random number. No instructions on prioritization of tasks. DT Levels: 1) threes and 2) sevens.		Mean Sway (1/3 degrees of angle of arc): (ST) DM: NR CN: NR (DT- Level 1) DM: NR CN: NR (DT- Level 2) DM: NR CN: NR		**Balance Task (ST):** DM group swayed more than CN ($p<0.05$). **Balance Task (DT):** No dual-task effect differences found between groups. *Authors reported that between group differences were observed once adjusted for BMI and depression status ($p<0.05$)* **Secondary Task:** No group differences found across levels.

Footnote:

AP: anterior-posterior plane; CN: control; COP: center-of-pressure; DM: people with diabetes mellitus; DT: dual-task; EC: eyes closed; EO: eyes open; ML: medial-lateral plane; MPN: mild peripheral neuropathy; NR: not reported; PN: neuropathy; RMS: root-mean square; SPN; severe peripheral neuropathy; ST: single-task; TTB: minimum time to boundary. Studies for which data was unable to be extracted as they only displayed information in figures are depicted by (*).

3.2. The Effect of Dual-Task Testing on Gait Performance in People with Diabetes

***3.2.1. Study Participants*:**

Seven studies examined the effect of dual-task testing on spatial-temporal gait parameters.[41–47] (Table 1). The total sample was 734 participants (DM: 209, DM(PN): 135, CN: 390) ranging from 24 to 315 per study. The average age (years) of participants across studies ranged from 60.3 to 77.7 for people with DM, 62.8 to 74.1 for people with DM and PN, and 70.0 to 77.9 for CN. Five of seven articles specified that their samples were people with type 2 diabetes[41, 42, 44, 46, 47], while two did not report the type of diabetes[43, 45]. The time since a DM diagnosis was reported by three studies and was between two to 14 ± 4.9 years in people with DM, and between five to 15 ± 13.3 years for people with DM(PN).[42, 43, 45] Holtzer et al.[44] specified that all of their participants with DM were either taking insulin or some oral hypoglycemic agent, while Roman de Mettelinge et al.[46] reported that close to 50% of participants in their DM and DM(PN) groups were taking insulin as part of their treatment. Across studies, participants were excluded based on the presence of neurological disorders, severe visual or auditory impairment, ulcer/amputations, or an inability to understand instructions or cognitive impairment. Additionally, six studies further reported on either BMI or glycated haemoglobin levels;[41–43, 45–47] while the reporting of other factors such as education, number of comorbidities, activity levels or falls history was provided by fewer studies.[43–47]

Every study stated that a diagnosis of DM was confirmed using medical records or by contacting the participant’s physician;[41–47] four further used glycated haemoglobin levels to confirm participant grouping[42, 43, 45, 46]. Importantly, only one study specified that a diagnosis of DM was confirmed using World Health Organization guidelines.[45] All studies reported the presence (or not) of neuropathy; however, only two reported on the type (polyneuropathy)[41, 42], and none reported on the cause, distribution, or current treatments for PN. Moreover, four studies grouped participants according to the severity of their PN: mild to moderate,[41] moderate,[42] or severe[45, 47]. Two studies[41, 45] used a combination of current or vibration perception thresholds, Semmes-Weinstein monofilament testing, and Rydel-Seiffer tuning fork or proprioceptive testing. The remaining two studies relied solely on vibration perception thresholds,[47] or clinical assessments of somatosensory and proprioceptive function[42]. Three studies reported that their controls or comparison groups were age-and/or sex-matched.[42, 43, 46]

Cognitive function was assessed in four studies.[42–44, 46] Of the three studies[43, 44, 46] that had participants with DM without PN, only one saw statistically lower scores in cognitive function, Mini-Mental State Examination and the clock drawing test, compared to CN.[46] A statistically significant lower performance in attention, reaction time, memory, the Montreal Cognitive Assessment, the Mini-Mental State Examination and the clock drawing test was observed in people with DM when compared to CN[46] or people with DM without PN[42, 46].

3.2.2. Gait Parameters:

No study assessed all five domains of gait (pace, rhythm, variability, asymmetry, and postural control). (Table 3). The most reported variables were related to pace. The domains of asymmetry and postural control were not examined by any of the included studies.

3.2.3. Gait and Dual-Task Testing Methods:

All studies examined usual straight path gait.[41–47] Spatial-temporal gait parameters were collected using pressure sensitive walkways[44–46], accelerometers[41, 47] or motion capture[42, 43]. Testing distances varied and ranged from 3.7 to 16.6 meters. Five studies reported their protocol allowed for the examination of steady state gait.[41–43, 45–47] One study examined gait outside and on three different surfaces (paved, gravel-rocks, and cobble stone).[41]

Regarding secondary tasks, most studies relied on the mental tracking task of arithmetic subtractions[41–43, 45–47], while others asked participants to recite the alphabet (working memory)[44], name animals (verbal fluency)[46], or to hold a tray of cups (motor)[45]. For number subtractions, participants were required to subtract by threes[41, 43, 46] or sevens[45], and two studies did not report specifics[42, 47]. Three studies tested more than one secondary task and made contrasts between a verbal fluency and a mental tracking task[42, 46] or a motor and a mental tracking task[45]. Details regarding the secondary task, such as the randomization of the starting number in arithmetic task protocols or a description of what entailed a “verbal fluency” task were missing in five studies.[42, 44–47] None of the studies examined different levels of difficulty on the secondary task of choice. Only three studies included information on the instructions given to participants regarding the prioritization of tasks, which was not to prioritize any one task.[41, 44, 46]

3.2.4. Dual-Task Testing on Pace:

A total of seven studies examined the domain of pace and reported on velocity (m or cm/s)[41–47], or stride or step length (m)[41, 42, 45, 46]. Gait velocity[46] and stride length[46] were significantly lower in people with DM compared to CN during single-task testing, with the exception of two studies which reported that people with DM had slower gait, but between group differences did not reach statistical significance[43, 44]. Similarly and compared to people with DM, those with DM and PN had significantly lower gait velocities[42, 45], and shorter stride or step lengths[41, 42, 45] during single-task testing; however, between group differences did not reach statistical significance for two of the four studies.[41, 46] In single-task conditions, people with DM and severe PN had significantly lower gait velocities than a CN group (medium effect size).[47]

Dual-task testing resulted in slower gait[43, 44, 46] and decreased stride or step length[46], yet only one study found that this effect was most pronounced in people with DM compared to CN,[46] one did not find any differences,[43] and another found that the CN group had a larger dual-task effect[44]. In people with DM and PN, dual-task testing significantly reduced gait velocity[42, 45–47] and stride or step length[42, 45], and this effect was found to be greater than in people with DM without neuropathy[42] or a CN group[47]. Kang et al.[47] further explained that once accommodating for differences in steady state gait velocity, parameters related to gait initiation (number of steps, distance, and ML sway) remained significantly higher in the group of people with DM and PN compared to CN. An additional study found contradictory results to those stated above[46]. Roman de Mettelinge et al.[46] found that although people with DM and PN had slower gait than those with DM without neuropathy, the differences between groups were not statistically significant (p=0.057). Author de Bruin et al.[41] also reported that gait speed and step length decreased with dual-task testing; however, groups contrasts were not performed. Instead, and across conditions, the authors reported that step length was shorter in people with severe PN compared to those with mild PN.

Three studies used more than one type of secondary task.[42, 45, 46] Paul et al.[45] saw that dual-task trials in which a motor task was used led to a larger decrease in step length but saw no changes in gait velocity compared to trials in which an arithmetic task was used. Author El-Tamawy, M. et al.[42] saw no difference in gait velocity or step length between dual-task tests with a verbal fluency versus an arithmetic task. Interestingly, Roman de Mettelinge et al.[46] determined that only in the group of people with DM and not CN did they observe that gait velocity was affected most by an arithmetic secondary task versus a verbal fluency task.

3.2.5. Dual-Task Testing on Rhythm:

A total of four studies examined the domain of rhythm and reported on cadence (steps/min)[41, 45], double support time (ms)[45, 46], or stride or step duration (s)[41, 42, 45]. Compared to CN, people with DM had longer double support times during single-task testing, although found not to be significantly different.[46] Individuals with DM and PN had significantly higher single-task gait cadence[45], double support times[45], and stride[42] and step[45] time durations than those without PN.

Dual-task testing resulted in significantly lower cadence[45], higher double support time[45, 46] and higher stride and step times[42, 45], which was most pronounced in people with DM and PN compared to those without neuropathy. Interestingly, and only in the study that examined gait outside, similar step duration and cadence was reported between people with DM and mild versus severe PN for both single-task and dual-task conditions.[41]

Two studies used more than one type of secondary task for their dual-task paradigm.[42, 45] For El-Tamawy, M. et al.[42] using a verbal fluency versus an arithmetic secondary task did not result in different gait performance. While for Paul et al.[45] the use of a motor secondary task resulted in significantly longer double support times across groups when compared to dual-task trials performing an arithmetic task.

3.2.6. Dual-Task Testing on Variability:

For single-task, stride length variability was higher in people with DM with or without PN compared to CN.[46] Dual-task testing resulted in increased stride length variability across groups; however, was not different between the DM groups or between DM groups and CN.

3.2.7. Dual-Task Testing on Secondary Task Performance:

Two studies reported on secondary task changes upon dual-task testing.[44, 45] Holtzer et al.[44] observed a significantly lower number of correct responses in people with DM compared to CN reciting alternate alphabet letters while dual-task gait testing. Similarly, Paul et al.[45] observed that people with DM and PN made significantly more errors (i.e., spilled more water) than people with DM without PN during the dual-task trials in which the motor task of carrying a tray of cups filled with water was used.

3.3. Methodological Reporting Quality

The average methodological reporting quality of the included studies was 14.50 ± 2.01 (range: 12 to 19) out of 32 (balance: 14.00 ± 1.41; gait: 14.71 ± 2.19). (Supplementary Table 3). None of the studies received scores for reporting items #8 and #9, external validity items #11 and #12, interval validity (bias) items #14, #15, #17, #19, or interval validity (selection bias) items #23-24 and #26.

Table **3**, Summary of results of the effect of dual-task testing on gait performance of people with diabetes.

Author	Gait Task and Secondary Task	Gait Domains			Main Results
		Pace	Rhythm	Variability	
de Bruin et al. 2012[41]	**Gait Task:** Usual pace on an outdoor pathway (1.2 x 16.6 m) composed of three different surfaces: 1) paved (7.4 m), 2) gravel-rocks (4.6 m), and 3) cobble stone (4.6 m) **Secondary Task (Mental tracking):** Continuously subtracting threes from 200. Instructed to not prioritize any one task.	Velocity (m/s): (ST) DM(SPN): 1.14 ± 0.37 DM(MPN): 1.39 ± 0.14 DM: 1.29 ± 0.14 (DT) DM(SPN): 1.09 ± 0.32 DM(MPN): 1.31 ± 0.28 DM: 1.18 ± 0.21 Step length (m): (ST) DM(SPN): 0.62 ± 0.12 DM(MPN): 0.73 ± 0.10 DM: 0.72 ± 0.06 (DT) DM(SPN): 0.63 ± 0.10 DM(MPN): 0.70 ± 0.13 DM: 0.70 ± 0.07	Cadence (steps/min): (ST) DM(SPN): 107.60 ± 15.00 DM(MPN): 115.00 ± 10.20 DM: 107.00 ± 5.80 (DT) DM(SPN): 103.40 ± 17.60 DM(MPN): 110.00 ± 9.30 DM: 101.40 ± 11.00 Step duration (s): (ST) DM(SPN): 0.55 ± 0.05 DM(MPN): 0.53 ± 0.05 DM: 0.56 ± 0.03 (DT) DM(SPN): 0.60 ± 0.12 DM(MPN): 0.55 ± 0.05 DM: 0.60 ± 0.08		**Gait Task (ST):** NR. **Gait Task (DT):** Dual-task led to deterioration of all gait parameters compared to single-task: velocity (p=0.001), cadence (p=0.003), step duration (p=0.004), and step length (p=0.029). Group differences found only for the step length variable across conditions, whereby DM(SPN) had shorter steps than DM(MPN) (p=0.046). **Secondary Task:** NR.
El-Tamawy et al. 2016[42]	**Gait Task:** Usual pace indoors (NR x 10.0 m). **Secondary Task (NR):** verbal fluency task (NR), arithmetic task (NR). No other details reported. No instructions on prioritization of tasks.	Velocity (m/s) (ST) DM(MoPN): 0.54 ± 0.17 DM: 1.80 ± 0.44 (DT- Verbal) DM(MoPN): 0.37 ± 0.12 DM: 1.73 ± 0.55 (DT- Arithmetic) DM(MoPN): 0.28 ± 0.10 DM: 1.63 ± 0.42 Stride length (m) (ST) DM(MoPN): 1.11 ± 0.17 DM: 1.68 ± 0.28 (DT- Verbal) DM(MoPN): 0.75 ± 0.12	Stride Duration (s) (ST) DM(MoPN): 0.74 ± 0.11 DM: 0.55 ± 0.04 (DT- Verbal) DM(MoPN): 1.01 ± 0.19 DM: 0.60 ± 0.15 (DT- Arithmetic) DM(MoPN): 0.98 ± 0.22 DM: 0.60 ± 0.08		**Gait Task (ST):** Group differences found across all variables whereby DM(MoPN) performed worse: velocity (p<0.001), stride length (p<0.001), and stride duration (p<0.001). **Gait Task (DT):** Dual-task performance was different between groups: velocity (p<0.001), stride length (p<0.001), and stride duration (p<0.001). *Differences between conditions (dual-task effect) only present in the DM(MoPN) group*

		DM: 1.65 ± 0.29 (DT- Arithmetic) DM(MoPN): 0.78 ± 0.15 DM: 1.64 ± 0.30			**Secondary Task:** NR.
Hewston et al. 2018[43](*)	**Gait Task:** 1) Usual pace, 2) fast pace (NR x 6 m). **Secondary Task (Mental Tracking):** Continuously subtracting threes from a random number (X<100). No instructions on prioritization of tasks.	Velocity (cm/s): (ST- Usual) DM: NR CN: NR (DT- Usual) DM: NR CN: NR (ST- Fast) DM: NR CN: NR (DT- Fast) DM: NR CN: NR			**Gait Task (ST):** No differences found between groups (p=0.078). **Gait Task (DT):** A dual-task effect was present in both groups and across both gait velocities (p<0.05). Dual-task resulted in slower gait which was most pronounced under fast trials (p<0.001) but not different between groups. **Secondary Task:** NR.
Holtzer et al. 2018[44]	**Gait Task:** Usual pace (1.2 x 4.3 m). **Secondary Task (Working Memory):** Reciting alternate letter of the alphabet. Instructed to not prioritize any one task.	Velocity (cm/s): (ST) DM: 74.91 ± 16.90 CN: 80.67 ± 17.50 (DT) DM: 63.69 ± 18.90 CN: 65.10 ± 18.80			**Gait Task (ST):** Group differences not observed. **Gait Task (DT):** Dual-task resulted in slower gait, which was found to be worse in CN versus DM (adjusted linear mixed effect model; p=0.023). **Secondary Task:** Worse secondary task performance in the DM group (p=0.008).
Kang et al. 2020[47]	**Gait Task:** Usual pace (12 m). **Secondary Task (Mental Tracking):** Continuously subtracting from a random number given by clinical researcher. No other details reported. No	Steady State Velocity (m/s): (ST) DM(SPN): 0.98 ± 0.04 CN: 1.10 ± 0.03 (DT) DM(SPN): 0.88 ± 0.04 CN: 1.02 ± 0.04 Gait Initiation Velocity (m/s):			**Gait Task (ST):** Group differences found across all variables: steady state speed (p=0.012), and gait initiation velocity (p=0.018). **Gait Task (DT):** Dual-task performance was worse in DM(SPN) compared to CN: steady state speed (p=0.009), and gait initiation velocity (p=0.025).

	instructions on prioritization of tasks.	*Gait velocity prior to steady state* (ST) DM(SPN): 0.99 ± 0.04 CN: 1.11 ± 0.03 (DT) DM(SPN): 0.89 ± 0.04 CN: 1.02 ± 0.04			*Results for both steady state and gait initiation when adjusted for age, body mass index and Falls Efficacy Scale (16-item). **Secondary Task:** NR.
Paul et al. 2009[45]	**Gait Task:** Usual pace (0.6 x 3.7 m). **Secondary Task (“Other”/Motor Task and Mental Tracking):** 1) Holding a tray of cups filled with water, 2) continuously subtracting sevens. No other details reported. No instructions on prioritization of tasks.	Velocity (cm/s) (ST) DM(SPN): 98.6 ± 26.9 DM: 114.3 ± 14.5 (DT- Motor) DM(SPN): 61.5 ± 12.6 DM: 83.3 ± 23.7 (DT- Arithmetic) DM(SPN): 73.8 ± 29.6 DM: 89.8 ± 18.4 Step length (cm) (ST) DM(SPN): 58.5 ± 11.6 DM: 61.7 ± 6.8 (DT- Motor) DM(SPN): 42.3 ± 9.1 DM: 49.3 ± 9.3 (DT-Arithmetic) DM(SPN): 50.0 ± 14.9 DM: 55.8 ± 9.3	Cadence (steps/min): (ST) DM(SPN): 100.0 ± 12.3 DM: 111.3 ± 9.8 (DT- Motor) DM(SPN): 87.6 ± 9.9 DM: 100.6 ± 13.2 (DT- Arithmetic) DM(SPN): 85.2 ± 15.6 DM: 96.4 ± 15.1 Step duration (s): (ST) DM(SPN): 0.61 ± 0.08 DM: 0.59 ± 0.16 (DT- Motor) DM(SPN): 0.69 ± 0.08 DM: 0.61 ± 0.09 (DT- Arithmetic) DM(SPN): 0.72 ± 0.13 DM: 0.64 ± 0.11 Double support time (ms): (ST) DM(SPN): 32.1 ± 3.7 DM: 29.6 ± 4.8 (DT- Motor) DM(SPN): 38.9 ± 2.7 DM: 34.5 ± 4.3 (DT- Arithmetic) DM(SPN): 36.4 ± 6.0 DM: 31.0 ± 2.3		**Gait Task (ST):** Group differences found across all variables: velocity (p<0.001), step length (p=0.013), step time (p=007), double support time (p<0.001), and cadence (p<0.001). **Gait Task (DT):** Dual-task resulted in worse performance across groups, but was most pronounced in DM(SPN)s except for the step time variable: velocity (p<0.001), step length (p<0.001), double support time (p<0.001), and cadence (p<0.001). Relative change (i.e., task cost) was greater in DM(SPN)s across both types of secondary tasks; although not statistically significant. **Secondary Task:** Performance decreased with dual-task (p<0.023). The DM(PN) had more errors than the DM group during dual-task trials with the motor task (p=0.006).

Roman de Mettelinge et al. 2013[46]	**Gait Task:** Usual pace (0.89 x 8.3 m). **Secondary Task (Verbal Fluency and Mental Tracking):** 1) Reciting animal names, 2) continuously subtracting threes from 40. Instructed to not prioritize any one task.	Velocity (cm/s) (ST) DM(PN): 62.4 ± 5.7 DM: 82.5 ± 5.7 CN: 103.4 ± 4.6 (DT- Verbal) DM(PN): 48.2 ± 5.7 DM: 65.7 ± 5.7 CN: 79.6 ± 4.6 (DT- Arithmetic) DM(PN): 41.1 ± 5.7 DM: 58.2 ± 5.7 CN: 82.0 ± 4.6 Stride length (cm) (ST) DM(PN): 81.5 ± 5.5 DM: 96.8 ± 5.5 CN: 118.0 ± 4.5 (DT- Verbal) DM(PN): 75.3 ± 5.5 DM: 90.2 ± 5.5 CN: 110.2 ± 4.6 (DT- Arithmetic) DM(PN): 69.8 ± 5.5 DM: 87.1 ± 5.5 CN: 111.8 ± 4.5	Double support time (ms): (ST) DM(PN): 0.97 ± 0.32 DM: 0.60 ± 0.32 CN: 0.38 ± 0.26 (DT- Verbal) DM(PN): 1.27 ± 0.32 DM: 1.71 ± 0.32 CN: 0.51 ± 0.26 (DT- Arithmetic) DM(PN): 1.39 ± 0.32 DM: 1.55 ± 0.32 CN: 0.53 ± 0.26	Stride length CoV (%): (ST) DM(PN): 5.68 ± 0.80 DM: 4.94 ± 0.80 CN: 3.05 ± 0.65 (DT- Verbal) DM(PN): 9.17 ± 0.80 DM: 7.37 ± 0.80 CN: 5.14 ± 0.65 (DT- Arithmetic) DM(PN): 9.00 ± 0.81 DM: 6.45 ± 0.81 CN: 4.90 ± 0.65	**Gait Task (ST):** Group differences observed, DM(PN) and DM versus CN across all variables with the exception of double support time: velocity (p<0.001), stride length (p<0.001), and stride length CoV (p=0.010). No statistically significant differences reported between DM(PN) and DM. **Gait Task (DT):** Group differences observed, DM(PN) and DM versus CN across all variables: velocity (p<0.001), stride length (p<0.001), double support time (p<0.005), and stride length CoV (p<0.001). Dual-task resulted in worse performance across all variables and found to be greater for DM in stride velocity (p=0.035). **Secondary Task:** NR.

Footnote:

AP: anterior-posterior plane; CN: control; CoV: coefficient of variation; DM: people with diabetes mellitus; DT: dual-task; ML: medial-lateral plane; MPN: mild peripheral neuropathy; MoPN: moderate neuropathy; NR: not reported; PN: neuropathy; SPN; severe peripheral neuropathy; ST: single-task. Studies for which data was unable to be extracted as they only displayed information in figures are depicted by (*).

4. DISCUSSION

During single-task balance tests in standing, people with DM with or without PN swayed faster and covered a greater area and distance in comparison to healthy controls. However, a dual-task balance effect was only observed for sway velocity in people with DM. In single-task gait testing, people with DM were slower, took fewer and shorter steps, and were more inconsistent with each stride compared to healthy adult controls. In dual-task gait testing, and especially in people with DM and PN, all aspects of gait further deteriorated and negatively affected how fast gait was, how many and how long steps were, and how stable individuals were during gait. Consistent with other existing literature in other patient groups, cognitive deficits in speed of processing, attention, memory, executive functions and global cognition were present in the participants with DM. Dual-task testing was able to emphasize deficits in functional performance in people with DM over single-task testing. The use of dual-task testing to identify people to commence rehabilitation interventions to improve functional performance and reduce the risk of falls should be explored.

To the authors' knowledge, this is the first systematic review that has assessed the effect of dual-task testing on the balance and gait of people with type 1 or type 2 DM. In 2016, Mustapa et al.[48] evaluated literature on the balance and gait of people with diabetic peripheral neuropathy, however only two studies with dual-task conditions were included. As our review was specific to dual-task testing in people with either type 1 or type 2 DM, with or without PN, we were able to identify an additional eight studies; five of which were published after 2016. Under dual-task testing during a static standing position, higher sway velocity was observed in people with DM. Through competition of cognitive resources, a reduced ability to precisely process deviations in their postural sway leads to overcompensation and the rapid imprecise activation of muscles around the ankles and hips.[33] As expected, the effect of dual-task testing was most apparent in gait, consistent with gait testing being more challenging on the cognitive-mobility relationship than maintaining a quiet stance. There were consistent findings across multiple studies of decreased pace and rhythm in people with DM and PN compared to CN, or people with DM without PN.

Balance and gait control issues are likely explained by various factors. Hindered somatosensory, muscular, visual and vestibular function is observed in people with a diagnosis of diabetes.[5] Dysregulation of blood glucose results in the overproduction of reactive oxygen species that damage the endothelial cells of blood vessels throughout the body.[49] Complications related to DM include nephropathy, neuropathy, retinopathy, and cardiovascular disease.[4] Additionally, close to 40% of older adults with DM are also living with at least three other chronic diseases,[50, 51] such as depression, obesity, hypertension, coronary artery disease, and congestive heart failure.[52–55] Appropriate motor responses require adequate sensory input, yet the loss of lower limb sensation is common among people with type 1 or 2 DM.[6–11, 56, 57] Moreover, people with diabetic PN experience paresthesia and impaired somatosensory function due to the degradation of nerve fibers.[58, 59] Importantly, diabetic PN can affect sensory, motor, or a combination of both nerve fibers, and affecting first the large myelinated nerves traveling to the feet and ankles before progressing proximally.[60] Motor responses to instability are time sensitive, however muscle weakness[61–65] and muscle atrophy[63, 64, 66, 67] are also reported in people with DM. In people with type 2 DM, deterioration of the musculoskeletal system is attributed to mitochondrial dysfunction as a consequence of increased concentrations of free fatty acid and triglycerides within tissues.[68] The degradation of these sensory and motor systems is important in light of the cognitive impairment seen in this population.[19, 20] Irrespective of the type, DM can result in vascular damage to brain structures such as the dorsolateral prefrontal cortex, posterior cingulate cortex, hippocampus, amygdala and ventricles[69] which are related to numerous cognitive processes[19, 20] and are considered critical cortical sites for the control of static and dynamic balance, including gait[70]. Cognitive dysfunction coupled with the degradation of lower limb sensation increase demands when performing simultaneous tasks, overloading the cognitive-mobility relationship and producing the disproportionately greater dual-task effect seen in those with DM and PN. Aside from issues brought upon by DM, or the comorbidities observed in this population, it is also likely that balance and gait impairments may in part be related to advanced age.[1] However, it is important to note that the majority of studies included in our systematic review either recruited sex-and age-matched controls or reported that groups had similar ages, thus other factors not related to age probably play a bigger role in the differential effect of dual-task on the balance and gait of people with DM with or without PN compared to healthy older adults. Therefore, as dual-task performance is an essential ability for everyday activities and reflects activities that lead to falls, healthcare professionals working with individuals with DM may look to dual-task testing as a method to discern those at a higher risk for falls.

The examination of dual-task balance or gait in people with type 1 or 2 DM is limited in scope of the testing protocols. For example, standing upright with feet shoulder-width apart (or close to) was the only static balance position tested. Similarly, and in all dual-task gait studies, only a straight path configuration was assessed even though curved paths offer an increased cognitive challenge that is reflective of real-life situations.[71] The negative effects of diabetes on cognitive processes[19, 20] and physical function[5] can be subtle. Therefore, the dual-task protocols may have not been challenging enough to appropriately tax the cognitive capacity in community-dwelling people with type 1 or type 2 DM. Additionally, most studies did not report on the performance of the secondary task, or the instructions on task prioritization given to participants. As a result, the performance of the secondary task may have been neglected, or task prioritization was inconsistent between studies which provide valuable information about task performance. Lastly, balance and gait are multidimensional complex tasks and subtle changes related to pathology may only be captured with the inclusion of parameters encompassing all aspects of balance and gait control.

To allow for the quantitative assessment of dual-task effects, it is recommended that future studies follow a standardized dual-task protocol and stricter reporting of participant characteristics, aim to reduce heterogeneity within patient samples, and include a wider range of balance and spatial-temporal gait parameters. A more detailed depiction of the effect of dual-task testing on mobility can only occur if future studies prioritize a full reporting of diabetes related participant characteristics, such as how DM was confirmed, type, duration, treatments, and other factors associated with DM (e.g., number of comorbidities, BMI, exercise status, etc.). For studies with a participant sample of people with DM and PN, it is critical to assess and report on the diagnosis criteria, type, severity, cause, distribution and treatment for PN. As diabetes affects multiple brain structures[69] impairing speed of processing, attention, memory, verbal fluency, visuospatial control and executive functions[19, 20], future dual-task studies should also report on cognitive performance, alongside the examination of cognitive processes other than working memory and the inclusion of different levels of difficulty for the secondary task. In our systematic review most studies involved verbal fluency or mental tracking tasks; however, discrimination and decision-making tasks, visuospatial, or motor tasks have yet to be thoroughly explored.[30] Moreover, participant instructions should also be reported as asking participants to focus on one task or another within a dual-task paradigm is known to affect results.[72] Lastly, future studies should aim to record secondary task performance. This would allow for the calculation of the cognitive task cost and for the assessment of task prioritization needed to understand if participants are making performance trade-offs by attending the posture/gait or cognitive task during dual-task testing.

Participants in the studies included in the systematic review typically had type 2 diabetes, were 50 years of age or older, and had a concurrent diagnosis of PN. As the protocol used to confirm a diagnosis, type, duration, treatment, and other associated DM factors were not consistently reported by studies, a sub-analysis was unable to be employed. Type 1 and 2 diabetes involve different mechanisms[49]; although they share some long-term complications they are considered and treated differently[4]. Therefore, the results of the studies included may be an overestimation of the dual-task effect on the balance and gait of people with DM. Moreover, few of the studies included assessed dual-task over an array of different protocols, settings, clinical participants characteristics, or recorded balance and gait parameters encompassing multiple domains. Regarding our systematic review protocol, three studies were excluded from the review as they were not published in English; but importantly, all met additional exclusion criteria as described within the English-written abstracts. A strength of the present systematic review was the optimal capture of all available literature through the use of six electronic databases, and that each article included underwent a methodological quality of reporting review. Although no one study reported on all items of the Downs & Black tool, missing information mainly pertained to follow-up and compliance specifics, and participant blinding and intervention randomization which are for the most part not applicable to the type of study design employed by the studies captured within our systematic review. As a result, all studies were deemed to have adequate methodology and were all considered during the qualitative synthesis of results. Additionally, our protocol included the need for a comparison group to be included in each study and for balance and gait parameters to be recorded using instrumented technology; thus, ensuring that precise recordings were reported.

5. CONCLUSIONS

Balance and gait are impaired in people with diabetes compared to healthy adults. Dual-task testing in people with DM is characterized by increased sway velocity in balance, and slower gait pace, rhythm and increased variability. Importantly and more consistently, dual-task effects were most pronounced in gait, affecting pace and rhythm domains in people with DM and PN compared to controls or people with DM without peripheral neuropathy. A small number of studies, and heterogeneous methodology and participant characteristics limited our ability to conclude with certainty that dual-task testing effects are more pronounced in people with DM without PN compared to healthy adults. Currently, the scope of dual-task research in people with DM is limited as a result of unstandardized protocols, the examination of few balance, gait and secondary tasks, and a lack of task cost and task prioritization calculations. As it is well documented that diabetes affects brain structure and function, and a cure does not currently exist, future research should continue to examine the cognitive-mobility relationship in people with DM in order to understand the increased prevalence of falls in this population.

6. LIST OF ABBREVIATIONS

AP - Anterior-posterior plane

CDR - Cognitive Drug Research cognitive assessment system

CN – Controls

COM – Center-of-mass

COP - Center-of-pressure and medio-lateral

CoV - Coefficient of variation

DM - Diabetes mellitus

DT - Dual-task

EC - Eyes closed

EO - Eyes open

ML - Medio-lateral plane

MoPN - Moderate neuropathy

MPN - Mild peripheral neuropathy

NR - Not reported

PN - Peripheral neuropathy

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PROSPERO - International Prospective Register of Systematic Reviews

RMS - Root-mean square

SPN - Severe peripheral neuropathy

ST - Single-task

T1D - Type 1 diabetes

T2D - Type 2 diabetes

TTB - Minimum time to boundary

7. CONFLICT OF INTEREST

The authors have no conflict of interest to report.

8. ACKNOWLEDGEMENTS

None to report.

9. SUPPORTIVE/SUPPLEMENTARY MATERIAL

Supplement Table **1**, Example search Web of Science search strategy.

Supplement Table **2**, List of articles reviewed for inclusion and reasons for exclusion.

Supplement Table **3**, Summary of Downs & Black methodological quality assessment for final study sample.

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Diabetes Mellitus and Falls in Older Adults: A Prospective Cohort Study. *PLoS One* 2013; 8: e67055.

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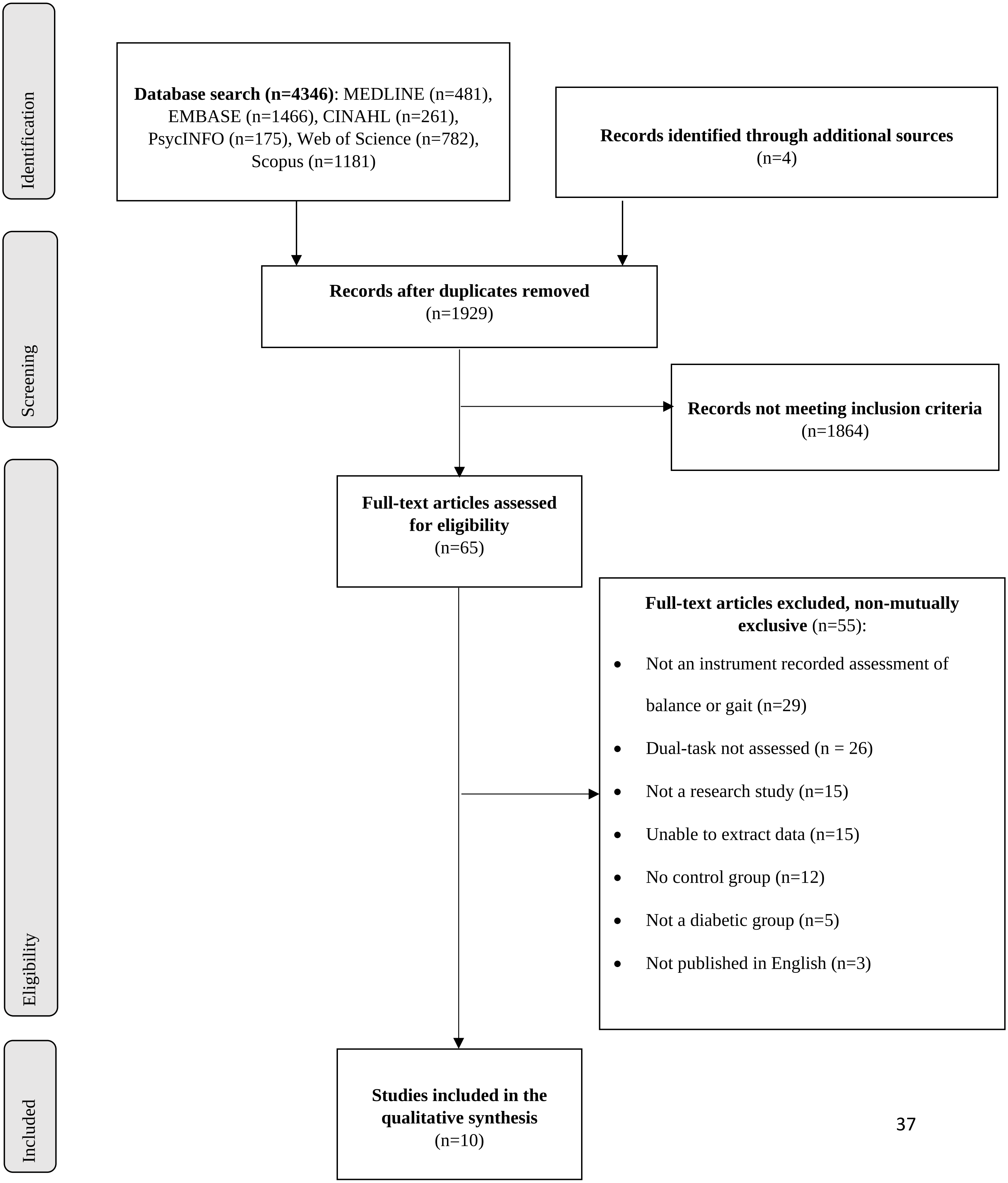
Figure **1**, Flow diagram of literature search as per PRISMA guideline.



Supplementary Table **1**, Example of search strategy for Web of Science database.

Topics (“All fields”)*	**Key terms and operators**
Groping #1: population	“diabetes mellitus” (OR diabet* OR “type 1 diabetes” OR “type 2 diabetes”)
“AND”	
Groping #2: outcome	balance (OR equilibrium OR posture OR stabilometry OR sway OR gait OR walking OR ambulation OR mobility OR kinetics OR kinematics)
“AND”	
Grouping #3: intervention	dual-task (OR “multi-task” OR “secondary task”).

*No filtering, restrictions or limitations applied

Supplementary Table **2**, List of full-text articles reviewed for inclusion and reasons for exclusion.

Article	**Number of exclusion criteria met**	**Reason(s) for exclusion**
Alvarenga, P. P., Pereira, D. S., & Anjos, D. (2010). Functional mobility and executive function in elderly diabetics and non-diabetics. Brazilian Journal of Physical Therapy, 14(6), 491-496.	1	Not an instrumented assessment
Allet, L., Armand, S., De Bie, R. A., Golay, A., Pataky, Z., Aminian, K., & De Bruin, E. D. (2009). Clinical factors associated with gait alterations in diabetic patients. Diabetic Medicine, 26(10), 1003-1009.	2	No control group, dual-task not assessed
Araki, A., Murotani, Y., & Aoyagi, Y. (2002). Comprehensive geriatric assessment and treatment of elderly diabetic patients. Nihon Ronen Igakkai zasshi. Japanese journal of geriatrics, 39(4), 396-399.	2	Not published in English, dual-task not assessed
Al-Momani, M., Al-Momani, F., Alghadir, A. H., Alharethy, S., & Gabr, S. A. (2016). Factors related to gait and balance deficits in older adults. Clinical interventions in aging, 11, 1043.	4	Not a diabetic group, no control group, dual-task not assessed, not an instrumented assessment
Arovah, N. I., Kushartanti, B. M. W., Washington, T. L., & Heesch, K. C. (2018). Walking with Diabetes (WW-DIAB) programme a walking programme for Indonesian type 2 diabetes mellitus patients: A pilot randomised controlled trial. SAGE Open Medicine, 6, 2050312118814391.	3	No control group, dual-task not assessed, not an instrumented assessment
Arvanitakis, Z., Wilson, R. S., Schneider, J. A., Bienias, J. L., Evans, D. A., & Bennett, D. A. (2004). Diabetes mellitus and progression of rigidity and gait disturbance in older persons. Neurology, 63(6), 996-1001.	2	Dual-task not assessed, not an instrumented assessment
Azizan, A., Anum, A., & Alias, A. (2019). Is there a link between physical, cognitive and fear of falls among elderly with diabetes mellitus? Journal of ASIAN Behavioural Studies, 4(13), 39-50.	1	Not an instrumented assessment
Bisson, E. J., Hewston, P. A., & Deshpande, N. (2013). Dual-Task stair negotiation of older adults: Effects of type 2 diabetes. Canadian journal of diabetes, 37, S52.	2	Not a research study (abstract), unable to extract data
Blackwood, J. (2018). Cognitive function and falls in older adults with type 2 diabetes mellitus. Journal of geriatric physical therapy (2001).	2	Dual-task not assessed, not an instrumented assessment
Brach, J. S., Talkowski, J. B., Strotmeyer, E. S., & Newman, A. B. (2008). Diabetes mellitus and gait dysfunction: possible explanatory factors. Physical therapy, 88(11), 1365-1374.	1	Dual-task not assessed
Chiba, Y., Kimbara, Y., Kodera, R., Tsuboi, Y., Sato, K., Tamura, Y., Mori S., & Araki, A. (2015). Risk factors associated with falls in elderly patients with type 2 diabetes. Journal of diabetes and its complications, 29(7), 898-902.	2	Dual-task not assessed, not an instrumented assessment
Chung, C. C., Maldonado, D. A. P., Jor'dan, A. J., Alfaro, F. J., Lioutas, V. A., Núñez, M. Z., & Novak, V. (2018). Lower cerebral vasoreactivity as a predictor of gait speed decline in type 2 diabetes mellitus. Journal of neurology, 265(10), 2267-2276.	1	Not an instrumented assessment
Coelho Junior, H. J., Callado Sanches, I., Doro, M., Asano, R. Y., Feriani, D. J., Brietzke, C., Gonçalves I.D., Uchida M.C., Capeturo E.C., & Rodrigues, B. (2018). Multicomponent exercise improves hemodynamic parameters and mobility, but not maximal walking speed, transfer capacity, and executive function of older type ii diabetic patients. BioMed research international, 2018, 4832851-4832851.	1	Not an instrumented assessment
Courtemanche, R., Teasdale, N., Boucher, P., Fleury, M., Lajoie, Y., & Bard, C. (1996). Gait problems in diabetic neuropathic patients. Archives of physical medicine and rehabilitation, 77(9), 849-855.	2	Not an instrumented assessment, unable to extract data

Cui, X., Abduljalil, A., Manor, B. D., Peng, C. K., & Novak, V. (2014). Multi-scale glycemic variability: A link to gray matter atrophy and cognitive decline in type 2 diabetes. PloS one, 9(1), e86284.	2	Dual-task not assessed, not an instrumented assessment
Dai, W., Duan, W., Alfaro, F. J., Gavrieli, A., Kourtelidis, F., & Novak, V. (2017). The resting perfusion pattern associates with functional decline in type 2 diabetes. Neurobiology of aging, 60, 192-202.	1	Not an instrumented assessment
de Mettelinge, T. R., Cambier, D., Calders, P., Van Den Noortgate, N., & Delbaere, K. (2013). Understanding the relationship between type 2 diabetes mellitus and falls in older adults: A prospective cohort study. PloS one, 8(6), e67055.	1	Dual-task not assessed
Deshpande, N., Hewston, P., & Aldred, A. (2017). Sensory functions, balance, and mobility in older adults with type 2 diabetes without overt diabetic peripheral neuropathy: A brief report. Journal of Applied Gerontology, 36(8), 1032-1044.	1	Not an instrumented assessment
Duignan, A., Kenny, R., Savva, G., Cronin, H., & Donoghue, O. (2013). Single and dual-task gait in older adults with diabetes mellitus: Preliminary analyses from the TILDA study. Age and Ageing, 42(suppl_2).	2	Not a research study (abstract), unable to extract data
Dyer, A., Killane, I., Bourke, N., Woods, C., Gibney, J., O'Neill, D., Reilly, R., & Kennelly, S. (2019). 84 Does Dual-Task Gait Speed Predict Cognitive Performance in Midlife Type 2 Diabetes? Baseline Results from the ENBIND Study. Age and Ageing, 48.	2	Not a research study (abstract), unable to extract data
Engelhardt, P., Dobrodziej, K., Kuchma, V., Lipton, A., & Porreca, A. (2015). Gait and balance impairments in individuals with type II diabetes mellitus (Doctoral dissertation, Utica College).	1	Not a research study (dissertation)
Espeland, M. A., Lipska, K., Miller, M. E., Rushing, J., Cohen, R. A., Verghese, J., McDermott, M.M., King, A.C., Strotmeyer, E.S., Blair, S.N., & Pahor, M. (2017). Effects of physical activity intervention on physical and cognitive function in sedentary adults with and without diabetes. The Journals of Gerontology: Series A, 72(6), 861-866.	2	Dual-task not assessed, not an instrumented assessment
Gorniak, S. L., Ray, H., Lee, B. C., & Wang, J. (2020). Cognitive–Motor Impairment in Manual Tasks in Adults With Type 2 Diabetes. OTJR: Occupation, Participation and Health, 40(2), 113-121.	2	Dual-task not assessed, not an instrumented assessment
Ferreira, M. C., Tozatti, J., Fachin, S. M., Oliveira, P. P. D., Santos, R. F. D., & Silva, M. E. R. D. (2014). Reduction of functional mobility and cognitive capacity in type 2 diabetes mellitus. Arquivos Brasileiros de Endocrinologia & Metabologia, 58(9), 946-952.	3	Not published in English, dual-task not assessed, not an instrumented assessment
Gomez, P., Gala C., Vigara M., Chung M., Lazaro M., & Gil Gregorio P. (2011). Profile of old diabetic patients with repeated falls. European Geriatric Medicine, 2, S24-S206.	4	Not a diabetic group, no control group, dual-task not assessed, not an instrumented assessment
Gorniak, S. L. (2017). Cognitive-motor impairment during balance in adults with type ii diabetes. Circulation, 136(suppl_1), A14656-A14656.	2	Not a research study (abstract), unable to extract data
Hamdani, N., & Yadav, R. (2017). Correlation between walking tests and psychological factors after brain gym exercise in diabetic individuals. Indian Journal of Physiotherapy & Occupational Therapy, 11(4).	1	Unable to extract data
Hewston, P. A., Bisson, E. J., & Deshpande, N. (2013). Dual-Task walking performance of older adults with diabetes mellitus: Effects of time constraints. Canadian Journal of Diabetes, 37, S51-S52.	3	Not a research study (abstract), unable to extract data, not an instrumented assessment
Hewston, P., Garcia, A., Alvarado, B., & Deshpande, N. (2018). Fear of falling in older adults with diabetes mellitus: The IMIAS Study. Canadian Journal on Aging/La Revue canadienne du vieillissement, 37(3), 261-269.	2	Dual-task not assessed, not an instrumented assessment

Inzitari, M., Metti, A., Rosano, C., Udina, C., Pérez, L. M., Carrizo, G., Verghese, J., Newman, A.B., Studenski, S., & Rosso, A. L. (2019). Qualitative neurological gait abnormalities, cardiovascular risk factors and functional status in older community-dwellers without neurological diseases: The healthy brain project. Experimental gerontology, 124, 110652.	4	Not a diabetic group, no control group, dual-task not assessed, not an instrumented assessment
Justice, J. N., Pierpoint, L. A., Mani, D., Schwartz, R. S., & Enoka, R. M. (2014). Motor function is associated with 1, 25 (OH) 2 D and indices of insulin–glucose dynamics in non-diabetic older adults. Aging clinical and experimental research, 26(3), 249-254.	4	Not a diabetic group, no control group, dual-task not assessed, not an instrumented assessment
Kang, G. E., Zahiri, M., Lepow, B., Saleem, N., & Najafi, B. (2019). The effect of daily use of plantar mechanical stimulation through micro-mobile foot compression device installed in shoe insoles on vibration perception, gait, and balance in people with diabetic peripheral neuropathy. Journal of diabetes science and technology, 13(5), 847-856.	1	Unable to extract data
Kang, G. E., Yang, J., & Najafi, B. (2020). Does the presence of cognitive impairment exacerbate the risk of falls in people with peripheral neuropathy? An application of body-worn inertial sensors to measure gait variability. Sensors, 20(5), 1328.	1	Not a diabetic group
Karmakar, S., Rashidian, H., Chan, C., Liu, C., & Toth, C. (2014). Investigating the role of neuropathic pain relief in decreasing gait variability in diabetes mellitus patients with neuropathic pain: a randomized, double-blind crossover trial. Journal of neuroengineering and rehabilitation, 11(1), 125.	2	No control group, dual-task not assessed
Kera, T., Kawai, H., Hirano, H., Kojima, M., Watanabe, Y., Fujiwara, Y., Ihara, K., & Obuchi, S. (2018). Comparison of body composition and physical and cognitive function between older Japanese adults with no diabetes, prediabetes and diabetes: A cross-sectional study in community-dwelling Japanese older people. Geriatrics & gerontology international, 18(7), 1031-1037.	2	Dual-task not assessed, not an instrumented assessment
Kosarian, Z., Ghanavati, T., Zakerkish, M., Mehravar, M., Pourreza, S., & Rahimzadeh, S. (2016). The association between duration of diabetes and balance impairment in people with diabetic neuropathy. Iranian Journal of Endocrinology and Metabolism, 18(3), 173-179.	3	Not published in English, dual-task not assessed, not an instrumented assessment
Kutty, N. A. M., & Majida, N. A. L. (2013). Effects of multisensory training on balance and gait in persons with type 2 diabetes: a randomised controlled trial. Disability, CBR & Inclusive Development, 24(2), 79-91.	2	Dual-task not assessed, not an instrumented assessment
Lee, C. G., Schwartz, A. V., Yaffe, K., Hillier, T. A., LeBlanc, E. S., Cawthon, P. M., & Study of Osteoporotic Fractures Research Group. (2013). Changes in physical performance in older women according to presence and treatment of diabetes mellitus. Journal of the American Geriatrics Society, 61(11), 1872-1878.	2	Dual-task not assessed, not an instrumented assessment
Li, Y., Wang, S., & Dong, B. (2014). Associations of frailty and functional status in elderly patients with type 2 diabetes. Journal of the American Geriatrics Society, 62.	1	Not a research study (clinical recommendations)
Maguire, F., Gibney, J., Reilly, R., & Kennelly, S. (2018). Gait and cognition in the clinic–A pilot study of patients with type 2 diabetes mellitus. Age and Ageing, 47(suppl_5).	2	Not a research study (abstract), unable to extract data
Maguire, F., Reilly, R., & Kennelly, S. (2017). Midlife gait abnormalities in people with type 2 diabetes–data from TILDA. Age and Ageing, 46.	2	Not a research study (abstract), unable to extract data
Petrova, D., Irikeva, M., Stambolieva, K. (2016). Effect of cognitive task on the maintaining of postural stability in patients with type 2 diabetes mellitus and peripheral neuropathy. Clinical Neurophysiology, 127: e93.	2	Not a research study (abstract), unable to extract data
Richerson, S. J. (2003). Effects of diabetes and aging on posture and acceleration thresholds during lateral translations (Doctoral dissertation, Louisiana Tech University).	1	Not a research study (dissertation)

Rucker, J. L. (2014). Multi-tasking, executive function, and functional abilities in older adults with type 2 diabetes mellitus (Doctoral dissertation, University of Kansas).	1	Not a research study (dissertation)
Rucker, J. L., McDowd, J. M., & Kluding, P. M. (2012). Executive function and type 2 diabetes: Putting the pieces together. Physical therapy, 92(3), 454-462.	1	Study is a literature review
Rucker, J. L., McDowd, J. M., Mahnken, J. D., Burns, J. M., Sabus, C. H., Britton-Carpenter, A. J., Utech, N. B., & Kluding, P. M. (2017). Multitasking in older adults with type 2 diabetes: A cross-sectional analysis. PloS one, 12(10), e0186583.	1	Not an instrumented assessment
Salsabili, H., Bahrpeyma, F., Forogh, B., & Rajabali, S. (2011). Dynamic stability training improves standing balance control in neuropathic patients with type 2 diabetes. Journal of rehabilitation research & development, 48(7).	2	No control group, dual-task not assessed
Son, J., Ashton-Miller, J. A., & Richardson, J. K. (2010). Do ankle orthoses improve ankle proprioceptive thresholds or unipedal balance in older persons with peripheral neuropathy? American journal of physical medicine & rehabilitation/Association of Academic Physiatrists, 89(5), 369.	3	No control group, dual-task not assessed, not an instrumented assessment
Suhl, E., Desrochers, L., Bonsignore, P., Sternthal, A., Giusti, J., & Munshi, M. N. (2009, June). Higher exercise capacity in older adults with diabetes is associated with better self-care ability and less diabetes-related stress. Diabetes, 58, A97-A97.	2	Not a research study (abstract), unable to extract data
Sun, B., & Ren, J. (2016). Motor behavior affects serum BDNF, MG and cognitive function in elderly patients with T2DM. Diabetes-metabolism research and reviews, 32, S2: 37-37.	2	Not a research study (abstract), unable to extract data
Van Geffen, J. A., Dijkstra, P. U., Hof, A. L., Halbertsma, J. P. K., & Postema, K. (2007). Effect of flat insoles with different Shore A values on posture stability in diabetic neuropathy. Prosthetics and orthotics international, 31(3), 228-235.	1	Unable to extract data
Vinik, A. I., Vinik, E. J., Colberg, S. R., & Morrison, S. (2015). Falls risk in older adults with type 2 diabetes. Clinics in geriatric medicine, 31(1), 89-99.	1	Study is a literature review
Wettasinghe, A., Dissanayake, D., Allet, L., Katulanda, P., & Lord, S. (2019). 126 Development of a Falls Prediction Tool for People with Diabetes Mellitus. Age and Ageing, 48(Supplement_4).	5	Not a research study (abstract), no control group, dual-task not assessed, not an instrumented assessment, unable to extract data
Wrobel, J. S., Ammanath, P., Le, T., Luring, C., Wensman, J., Grewal, G. S., Najafi, B., & Pop-Busui, R. (2014). A novel shear reduction insole effect on the thermal response to walking stress, balance, and gait. Journal of diabetes science and technology, 8(6), 1151-1156.	1	No control group
Zhang, M., Liu, T., Li, C., Wang, J., & Wu, D. (2019). Physical performance and cognitive functioning among individuals with diabetes: Findings from the China health and retirement longitudinal study baseline survey. Journal of advanced nursing, 75(5), 1029-1041.	3	No control group, dual-task not assessed, not an instrumented assessment

Supplementary Table **3**, Summary of Downs & Black methodological quality assessment for papers included in the systematic review.

Author	**Item#**																											**Total Score**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	
Dual-task Balance																												
Gorniak et al. 2019[34]	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	0	0	13
Hijmans et al. 2008[35]	0	1	1	1	2	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	0	0	0	13
Smith et al. 2014[36]	1	1	1	1	2	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	0	1	16
Dual-task Gait																												
de Bruin et al. 2012[37]	1	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	0	0	0	13
El-Tamawy et al. 2016[38]	1	1	1	0	0	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	0	0	12
Hewston et al. 2018[39]	1	1	1	1	2	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	0	0	15
Holtzer et al. 2018[40]	1	1	1	1	2	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	1	1	0	0	1	0	3	19
Kang et al. 2020[43]	1	1	1	1	2	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	0	1	16
Paul et al. 2009[41]	1	1	1	1	2	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	0	0	15
Roman de Mettelinge et al. 2013[42]	1	1	1	1	2	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	13
Average Score ± SD																												14.50 ± 2.01