Predicting falls in the elderly: do dual-task tests offer any added value? A systematic review

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Mina spent a year working alongside some great researchers at Neuroscience Research Australia. Most of his work focused on falls in the elderly, which is very relevant today thanks to our ageing population.

The issue of falls is a significant health concern in geriatric medicine and a major contributor to morbidity and mortality in those over 65 years of age. Gait and balance problems are responsible for up to a quarter of falls in the elderly. It is unclear whether dual-task assessments, which have become increasingly popular in recent years, have any added benefit over single-task assessments in predicting falls. A previous systematic review that included manuscripts published prior to 2006 could not reach a conclusion due to a lack of available data. Therefore, a systematic review was performed on all dual-task material published from 2006 to 2011 with a focus on fall prediction. The review included all studies published between 2006-2011 and available through PubMed, EMBASE, PsycINFO, CINAHL and the Cochrane Central Register of Controlled Trials databases that satisfied inclusion and exclusion criteria utilised by the previous systematic review. A total of sixteen articles met the inclusion criteria and were analysed for qualitative and quantitative results. A majority of the studies demonstrated that poor performance during dual-task assessments was associated with a higher risk of falls in the elderly. Only three of the 16 articles provided statistical data for comparison of single- and dual-task assessments. These studies provided insufficient data to demonstrate whether dual-task tests were superior to single-task tests in predicting falls in the elderly. Further head-to-head studies are required to determine whether dual-task assessments are superior to single-task assessments in their ability to predict future falls in the elderly.

Introduction

Many simple tasks of daily living such as standing, walking or rising from a chair can potentially lead to a fall. Each year one in three people over the age of 65 living at home will experience a fall, with five percent requiring hospitalisation. [1, 2] Gait and balance problems are responsible for 10-25% of falls in the elderly, only surpassed by 'slips and trips,' which account for 30-50%. [2] Appropriate clinical evaluation of identifiable gait and balance disturbances, such as lower limb weakness or gait disorders, has been proposed as an efficient and cost-effective practice which can prevent many of these falls. As such, fall prevention programs have placed a strong emphasis on determining a patient's fall risk by assessing a variety of physiological characteristics. [2, 3]

Dual-task assessments have become increasingly popular in recent years, because they examine the relationship between cognitive function and attentional limitations, that is, a subject's ability to divide their attention. [4] The accepted model for conducting such tests involves a primary gait or balance task (such as walking at normal pace) performed concurrently with a secondary cognitive or manual task (such as counting backwards). [4, 5] Divided attention whilst walking may manifest as subtle changes in posture, balance or gait. [5, 6] It is these changes that provide potentially clinically significant correlations, for example, detecting changes in balance and gait after an exercise intervention. [5, 6] However, it is unclear whether a patient's performance during a dual-task assessment has any added benefit over a single-task assessment in predicting falls.

In 2008, Zijlstra *et al.* [7] produced a systematic review of the literature which attempted to evaluate whether dual-task balance assessments

are more sensitive than single balance tasks in predicting falls. It included all published studies prior to 2006 (inclusive), yet there was a lack of available data for a conclusion to be made. This was followed by a review article by Beauchet *et al.* [8] in 2009 that included additional studies published up to 2008. These authors concluded that changes in performance while dual-tasking were significantly associated with an increased risk of falling in older adults. The purpose of this present study was to determine, using recently published data, whether dual-task tests of balance and/or gait have any added benefit over single-task tests in predicting falls. A related outcome of the study was to gather data to either support or challenge the use of dual-task assessments in fall prevention programs.

A systematic review of all published material from 2006 to 2011 was performed, focusing on dual-task assessments in the elderly. Inclusion criteria were used to ensure only relevant articles reporting on fall predictions were selected. The method and results of included manuscripts were qualitatively and quantitatively analysed and compared.

Methods

Literature Search

A systematic literature search was performed to identify articles which investigated the relationship between falls in older people and balance/gait under single-task and dual-task conditions. The electronic databases searched were PubMed, EMBASE, PsycINFO, CINAHL and Cochrane Central Register of Controlled Trials. The search strategy utilised by Ziljstra *et al.* [7] was carried out. Individual search strategies were tailored to each database, being adapted from the following which was used in PubMed:

1. (**gait** OR **walking** OR **locomotion** OR **musculoskeletal equilibrium** OR **posture**)
2. (**aged** OR **aged, 80 and over** OR **aging**)
3. #1 AND #2
4. (**cognition** OR **attention** OR cognitive task(s) OR attention tasks(s) OR dual task(s) OR double task paradigm OR second task(s) OR secondary task(s))
5. #3 AND #4
6. #5 AND (**humans**)

Bold terms are MeSH (Medical Subjects Headings) key terms.

The search was performed without language restrictions and results were filtered to produce all publications from 2006 to March 2011 (inclusive). To identify further studies, the author hand-searched reference lists of relevant articles, and searched the Scopus database to identify any newer articles which cited primary articles.

Selection of papers

The process of selecting manuscripts is illustrated in Figure 1. Only articles with publication dates from 2006 onwards were included, as all relevant articles prior to this were already contained in the mini-review by Ziljstra *et al.* [7] Two independent reviewers then screened article titles for studies that employed a dual-task paradigm – specifically, a gait or balance task coupled with a cognitive or manual task – and included falls data as an outcome measure.

Article abstracts were then appraised to determine whether the dual-task assessment was used appropriately and within the scope of the present study; that is to: (1) predict future falls, or (2) differentiate between fallers and non-fallers based on retrospective data collection of falls. Studies were only considered if subjects' fall status was determined by actual fall events – the fall definitions stated in individual articles were accepted. Studies were included if participants were aged 65 years and older. Articles which focused on adult participants with a specific medical condition were also included. Studies that reported no results for dual-task assessments were included for descriptive purposes only. Interventional studies which used the dual-task paradigm to detect changes after an intervention were excluded, as were case studies, review articles or studies that used subjective

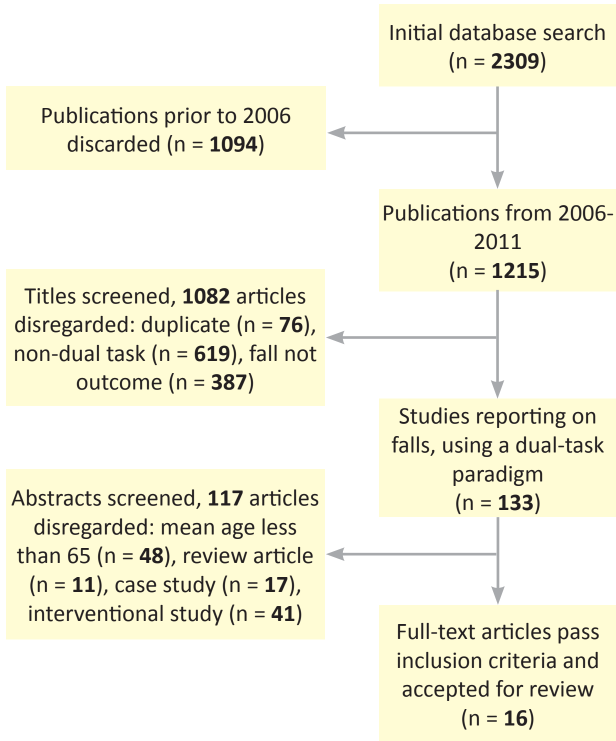

Figure 1. *Flow diagram illustrating study selection.*

Table 1A. *Retrospective studies – summary of main features.*

Study	Population	Sample size (% female)	Mean age (years ± SD)	Classification of fallers	Group sample size	Fall-data collection
Lindemann *et al.*, 2010 [23]	Patients with progressive supranuclear palsy	26 (54%)	67.5	Frequent fallers (>1 fall/month) OR infrequent fallers (≤1 fall/month)	18 frequent fallers & 8 infrequent fallers	Self-reported^
McCulloch *et al.*, 2010 [25]	Patients recovering from acute brain injury	24 (25%)	39.4 ± 13.3	Fallers (≥1 fall in previous 6 months) OR Non-fallers	13 fallers & 11 non-fallers	Self-reported~
Siu *et al.*, 2008 [10]	Community dwelling	24 (70.8%)	74.1 (HOA) & 81.0 (BIOA)	Balance impaired older adults (≥1 fall in previous 12 months) OR Healthy older adults	12 HOA & 12 BIOA	Self-reported^
Faulkner *et al.*, 2007 [12]	Community dwelling	370 (51.7%)	78 ± 3	Recurrent fallers (≥2 falls in previous 12 months) OR Non-recurrent fallers (≤1 fall in previous 12 months)	37 recurrent fallers & 333 non-recurrent fallers	Self-reported^
Melzer *et al.*, 2007 [13]	Self-care, residential facilities	100 (74%)	78.4 ± 5.7	Fallers (≥2 falls in previous 6 months) OR Non-fallers#	11 fallers & 71 non-fallers	Self-reported~
Springer *et al.*, 2006 [22]	Community dwelling	41	76.1 ± 4.8 (fallers) & 71.0 ± 5.9 (non-fallers)	Fallers (≥1 fall in previous 6 months) OR Non-fallers	17 fallers & 24 non-fallers	Self-reported~
Hyndman *et al.*, 2006 [24]	Recently discharged stroke patients	60 (41.7%)	66.5 ± 11.8 (stroke patients) & 62.3 ± 11.61 (control)	Stroke fallers OR Stroke non-fallers OR Control	36 stroke patients & 24 Control	Self-reported^
Toulotte *et al.*, 2006 [19]	Community dwelling	40 (100%)	70.4 ± 6.4 (fallers) & 67.0 ± 4.8 (non-fallers)	Fallers (≥1 fall in previous 24 months) OR Non-fallers	21 fallers & 19 non-fallers	History taken by two separate clinicians
Vaillant *et al.*, 2006 [20]	Community dwelling with osteoporosis	95 (100%)	73.4 ± 1.7	Fallers (≥1 fall in previous 12 months) OR Non-fallers	25 fallers & 70 non-fallers	Self-reported^

*DT = Dual-task, HOA = Healthy Older Adults, BIOA = Balance Impaired Older Adults, MCQ's = Multiple Choice Questions, AP = Anterior-Posterior, ML = Medial-Lateral, TUG = Timed Up & Go, ^ Over previous 12 months, ~ Over previous 6 months, * Only 'fast but safe' used during dual-task assessment, # In this particular study, subjects who fell only once were not included in either group* scoring systems to assess dual-task performance.

Analysis of relevant papers

Information on the following aspects was extracted from each article: study design (retrospective or prospective collection of falls), number of subjects (including gender proportion), number of falls required to be classified a 'faller', tasks performed and the corresponding measurements used to report outcome, task order and follow up period if appropriate.

Where applicable, each article was also assessed for values and results which allowed comparison between the single and dual-task assessments and their respective falls prediction. The appropriate statistical measures required for such a comparison include sensitivity, specificity, positive and negative predictive values, odds ratios or likelihood ratios. [9] The dual-task cost, or difference in performance between the single and dual-task, was also considered.

Results

The database search of PubMed, EMBASE, PsycINFO, CINAHL and Cochrane produced 1154, 101, 468, 502 and 84 references respectively. As alluded to by Figure 1, filtering results for publications between 2006-2011 almost halved results to a total of 1215 references. A further 1082 studies were omitted as they fell under the category of duplicates, non-dual task studies, or did not report falls as the outcome.

The 133 articles which remained reported on falls using a dual-task approach, that is, a primary gait or balance task paired with a secondary cognitive task. Final screening was performed to ensure that the mean age of subjects was at least 65, as well as to remove case studies, interventional studies and review articles. Sixteen studies met the inclusion criteria, nine retrospective and seven prospective fall studies, summarised by study design in Tables 1A and 1B respectively.

The number of subjects ranged from 24 to 1038, [10, 11] with half the studies having a sample size of 100 subjects or more. [11-18] Females were typically the dominant participants, comprising over 70% of the subject cohort on nine occasions. [10, 13, 14, 16-21] Eight studies

Table 1A (Continued). *Retrospective studies – summary of main features.*

Study	Balance/gait task	Cognitive/secondary task	Task order randomised	Outcome(s) measured	Fall rate (%)	DT performance associated with falls?
Lindemann *et al.*, 2010 [23]	7m walk (3 speeds: slow, normal and fast but safe*)	Serial subtraction by threes, starting from 97	No	Gait parameters (gait speed, stride length and cadence) Time of backward counting	8/26 (30.8%)	Yes
McCulloch *et al.*, 2010 [25]	6m walk, then turn and walk back	Numeric memory task	No	Walking time Recall accuracy	13/24 (54.2%)	No
Siu *et al.*, 2008 [10]	10m walk (normal pace), obstacle avoidance (normal pace)	Auditory stroop task (High or low pitch voices)	Yes	Gait parameters (temporal-distance parameters, range of motion and peak velocity of the centre of mass Verbal reaction time	12/24 (50%)	Yes
Faulkner *et al.*, 2007 [12]	Straight 20m walk (normal pace), turn walk (at 10m on the 20m path)	Push-button task, Visio-spatial decision task (clock face)	Yes	Walking time Reaction time (for push-button and visiospatial decision task)	37/370 (10%)	Yes
Melzer *et al.*, 2007 [13]	Voluntary step execution test	Visual stroop task	No	Step execution times	11/100 (11%)	Yes
Springer *et al.*, 2006 [22]	Continuous walking up and down a 25m path for 2 minutes (normal pace)	10 MCQs after hearing a passage of text (simple or complex), Serial subtraction of sevens	No	Swing time, gait variability and average gait speed	17/41 (41.5%)	Yes
Hyndman *et al.*, 2006 [24]	Balance: quiet standing Gait: straight 5m walk (normal pace)	Recall of 'shopping list'	No	Balance: sway in the AP and ML directions Gait: walking time, stride length and velocity	12/60 (20%)	Yes
Toulotte *et al.*, 2006 [19]	Balance: one-leg balance test (± vision) Gait: straight 10m walk (normal pace)	Holding a glass of water in dominant hand	No	Walking speed, cadence, stride time and step time	21/40 (52.5%)	Yes
Vaillant *et al.*, 2006 [20]	TUG, One-leg balance test	Serial subtraction by two or five, or addition by three	Yes	TUG	25/95 (26.3%)	No

*DT = Dual-task, HOA = Healthy Older Adults, BIOA = Balance Impaired Older Adults, MCQ's = Multiple Choice Questions, AP = Anterior-Posterior, ML = Medial-Lateral, TUG = Timed Up & Go, ^ Over previous 12 months, ~ Over previous 6 months, * Only 'fast but safe' used during dual-task assessment, # In this particular study, subjects who fell only once were not included in either group*

Table 1B. *Prospective studies – summary of main features.*

Study	Population	Sample size (% female)	Mean age (years ± SD)	Classification of fallers	Fall definition	Fall-data collection
Yamada *et al.*, 2011 [11]	Community dwelling	1038 (61.4%)	77 ± 8	#Fastest (230) OR Faster (258) OR Slower (264) OR Slowest (286)	"Any event that led to unplanned, unexpected contact with a supporting surface during walking"	Incident falls were collected by phone every month
Nordin *et al.*, 2010 [14]	Community dwelling	23 (72.2%)	78.0 (non-fallers) & 80.0 (fallers)	N/A	"An event in which the participant unintentionally came to rest on the floor or ground, regardless of the cause or the consequences of the fall"	Patient journal, mailed to authors monthly
Herman *et al.*, 2010 [15]	Community dwelling	262 (60.3%)	76.3 ± 4.3	Of 262, only 201 formed target cohort*	"Unintentionally coming to rest on a lower surface"	Incident falls were recorded on calendars and mailed monthly
Beauchet *et al.*, 2008 [16]	Senior housing facilities	213 (83.6%)	84.4 ± 5.5	N/A	"Unintentionally coming to rest on the ground, floor, or other lower level"	Incident falls were collected by phone every month
Beauchet *et al.*, 2008 [17]	Senior housing facilities	187 (84.5%)	84.8 ± 5.2	N/A	"Unintentionally coming to rest on the ground, floor, or other lower level"	Incident falls were collected by phone every month
Kressig *et al.*, 2008 [21]	Hospital inpatients	57 (77.2%)	85 ± 6.6	N/A	"Unintentionally coming to rest on the ground, floor, or other lower level"	Incident falls were collected by phone every month
Beauchet *et al.*, 2007 [18]	Senior housing facilities	187 (84.5%)	84.8 ± 5.2	N/A	"Unintentionally coming to rest on the ground, floor, or other lower level"	Incident falls were collected by phone every month

*DT = Dual-task, # Based on results of Timed Up & Go test, ^ Dual-task cost derived from walking speed, ~ Only for the elderly with high functional capacity (i.e. 'faster' and 'fastest' groups), $ Only for two of the five tasks (i.e. serial subtractions and carrying a cup), * Only the 201 non-fallers (at baseline) were included*

Table 1B (continued). *Prospective studies – summary of main features.*

Study	Balance/gait task	Cognitive/secondary task	Task order randomised?	Outcome(s) measured	Follow-up period	Fall rate	DT performance associated with falls?
Yamada *et al.*, 2011 [11]	Straight 15m walk (normal pace)	Cognitive: backward counting aloud from 100 Manual: carrying a ball	No	Incidence of falls & DT cost^	12 months	309/1038 (29.8%)	Yes~
Nordin *et al.*, 2010 [14]	Straight 10m walk (slow, normal and fast)	Carry cup, tray, cup & tray Naming animals Serial subtractions	No	1 or more falls & Gait parameters (step width, step time, step length)	12 months	110/230 (48%)	Yes$
Herman *et al.*, 2010 [15]	Up and down a straight 25m walk, for 2 minutes (normal pace)	Serial subtraction by threes	No	Incidence of falls & Gait variability	24 months	131/262 (50%)	Yes
Beauchet *et al.*, 2008 [16]	Straight 10m walk (normal pace)	Backward counting aloud from 50	Yes	First fall and recurrent falls & Walking speed whilst dual tasking	12 months	57/213 (26.8%)	Yes
Beauchet *et al.*, 2008 [17]	Straight 10m walk (normal pace)	Backward counting aloud from 50	Yes	First fall & Mean walking time during dual task	12 months	54/187 (28.9%)	No
Kressig *et al.*, 2008 [21]	Straight 10m walk (normal pace)	Backward counting aloud from 50	No	First fall & Coefficient variation of stride time variability during DT	12 months	10/57 (21.3%)	Yes
Beauchet *et al.*, 2007 [18]	Straight 10m walk (normal pace)	Backward counting aloud from 50	Yes	First fall & Improved counting performance	12 months	54/187 (28.9%)	Yes

*DT = Dual-task, # Based on results of Timed Up & Go test, ^ Dual-task cost derived from walking speed, ~ Only for the elderly with high functional capacity (i.e. 'faster' and 'fastest' groups), $ Only for two of the five tasks (i.e. serial subtractions and carrying a cup), * Only the 201 non-fallers (at baseline) were included*

Table 2. *Studies reporting on the predictive ability of the single and/or dual-task tests.*

	Sensitivity (%)*	Specificity (%)*	PPV (%)*	NPV (%)*	Odds Ratio: OR (95% CI) p-value	Likelihood Ratio: LR (95% CI)	Notes
Lindemann *et al.*, 2010 [23]	13/18 (72.2)	6/8 (75.0)	13/15 (86.7)	6/11 (54.5)	N/A	N/A	Figures based on number of subjects with 'Altered walking pattern during DT' (i.e. decreased stride length and increased cadence).
Faulkner *et al.*, 2007 [12]	N/A	N/A	N/A	N/A	PUSH-BUTTON TASK [a] straight walk: 1.12 (0.87-1.44) p= 0.37 [b] turn walk: 1.21 (0.97-1.51) p= 0.10 VISIO-SPATIAL TASK [a] straight walk: 1.34 (1.06-1.69) p= 0.01 [b] turn walk: 1.23 (0.99-1.51) p= 0.06	N/A	Odds ratio based on walking-time and history of recurrent falls. Adjusted for randomised task order and cane use.
Melzer *et al.*, 2007 [13]	9/11 (81.8)	N/A	N/A	N/A	N/A	N/A	Foot contact <1,100ms used by authors as cut off.
Yamada *et al.*, 2011 [11]	N/A	N/A	N/A	N/A	FASTEST GROUP MT cost: 1.068 (1.04-1.10) p <.001 FASTER GROUP CT cost: 1.03 (1.01-1.04) p <.001	N/A	MT and CT cost^ used to determine OR of future falls. No other balance/gait data reported.
Nordin *et al.*, 2010 [14]	N/A	N/A	N/A	N/A	SERIAL SUBTRACTION 2.3 (1.02-5.36)$ CARRYING A CUP [a] 0.2 (0.1-0.5)% [b] 0.4 (0.2-0.9)# [c] 0.3 (0.2-0.7)~	SERIAL SUBTRACTION 0.5 (0.3-0.9)@ CARRYING A CUP 2.3 (1.3-3.9)+	Figures based on DT cost^. LR boundaries for prognostic guidance were ≤ 0.5 or ≥ 2.0.
Herman *et al.*, 2010 [15]	N/A	N/A	N/A	133/193 (69.9)	Univariate analysis: 1.47 (1.13-1.92) Multivariate analysis: 1.39 (0.99-1.96)	N/A	OR based on gait variability during DT. Univariate and multivariate analysis reported.
Beauchet *et al.*, 2008 [16]	12/72 (16.7)	133/141 (94.3)	12/20 (60.0)	76/95 (80.0)	Single-task: 0.96 (0.94-0.99) p= 0.002 Dual-task: 0.60 (0.41-0.85) p= 0.005	N/A	OR based on walking speed and recurrent falls (i.e. ≥2). Authors calculated that decreased walking speed corresponds to increased risk of recurrent falls, 1.04 for single-task and 1.67 for DT.
Beauchet *et al.*, 2008 [17]	35/54 (64.8)	76/133 (57.1)	35/92 (38.0)	41/44 (93.2)	Single-task: 1.1 (1.0-1.2) p= 0.037 Dual-task: 1.1 (0.9-1.1) p= 0.012	N/A	OR based on walking time and first fall event.
Kressig *et al.*, 2008 [21]	7/10 (70.0)	41/47 (87.2)	7/13 (53.9)	120/133 (90.2)	Single-task: 13.3 (1.6-113.6) p= 0.018 Dual-task: 8.6 (1.9-39.6), p= 0.006	N/A	OR based on coefficient of variation of stride time and first fall event.
Beauchet *et al.*, 2007 [18]	45/52 (86.5)	117/130 (90.0)	46/54 (85.2)	120/133 (90.2)	N/A	N/A	-

OR = Odds ratio, CI = Confidence intervals, N/A = Data not available, LR = Likelihood ratio, DT = Dual-task, MT = Manual task, CT = Cognitive task

** Predictive value of the dual-task test, ^ The difference in performance between single and dual-tasks, $ If DT cost of mean step-width is ≥ ±3.6mm, % If DT cost in mean step-width is ≥ ±3.7mm, # If DT cost in step-length variability is ≥ ±7.1cm, ~ If DT cost in mean step-time is ≥ ±5.2ms, @ If DT cost in mean step-width ≤ ±3.6mm, + If DT cost in mean step-width ≤ ±3.7mm*

investigated community-dwelling older adults, [10-12, 14, 15, 19, 20, 22] four examined older adults living in senior housing/residential facilities [13, 16-18] and one focused on elderly hospital inpatients. [21] A further three studies exclusively investigated subjects with defined pathologies, specifically progressive supranuclear palsy, [23] stroke [24] and acute brain injury. [25]

Among the nine retrospective studies, the fall rate ranged from 10.0% to 54.2%. [12, 25] Fall rates were determined by actual fall events; five studies required subjects to self-report the number of falls experienced over the preceding twelve months, [10, 12, 20, 23, 24] three studies asked subjects to self-report over the previous six months [13, 22, 25] and one study utilised a history-taking approach, with subjects interviewed independently by two separate clinicians.

[19] Classification of subjects as a 'faller' varied slightly, with five studies reporting on all fallers (i.e. ≥ 1 fall), [10, 19, 20, 22, 25] three reporting only on recurrent fallers (i.e. ≥ 2 falls), [12, 13, 23] and one which did not specify. [24]

The fall rate for the seven prospective studies ranged from 21.3% to 50.0%. [15, 21] The number of falls per subject were collected during the follow-up period, which was quite uniform at twelve months, [11, 14, 16-18, 21] except for one study which continued data collection for 24 months. [15] The primary outcome measure during the follow-up period was fall rate, based on either the first fall [16-18, 21] or incidence of falls. [11, 14, 15]

The nature of the primary balance/gait task varied between studies. Five studies investigated more than one type of balance/gait task. [10, 12, 19, 20, 24] Of the sixteen studies, ten required subjects to walk along a straight walkway, nine at normal pace [10, 11, 14, 16-19, 21, 24] and one at fast pace. [23] Three studies incorporated a turn along the walkway [15, 22, 25] and a further study comprised of both a straight walk and a separate walk-and-turn. [12] The remaining two studies did not employ a walking task of any kind, but rather utilised a voluntary step execution test [13], a Timed Up & Go test and a one-leg balance test. [20]

The type of cognitive/secondary task also varied between studies. All but three studies employed a cognitive task; one used a manual task [19] and two used both a cognitive and a manual task. [11, 14] Cognitive tasks differed greatly to include serial subtractions, [14, 15, 20, 22, 23] backward counting aloud, [11, 16-18, 21] memory tasks, [24, 25] stroop tasks [10, 13] and visuo-spatial tasks. [12] The single and dual-tasks were performed in a random order in six of the sixteen studies. [10, 12, 16-18, 20]

Thirteen studies recorded walking time or gait parameters as a major outcome. [10-12, 14-17, 19, 21-25] Of all studies, eleven reported that dual-task performance was associated with the occurrence of falls. A further two studies came to the same conclusion, but only in the elderly with high functional capacity [11] or during specific secondary tasks. [14] One prospective [17] and two retrospective studies [20, 25] found no significant association between dual-task performance and falls.

As described in Table 2, ten studies reported figures on the predictive ability of the single and/or dual-tasks; [11-18, 21, 23] some data was obtained from the systematic review by Beauchet *et al.* [8] The remaining six studies provided no fall prediction data. In predicting falls, dual-task tests had a sensitivity of 70% or greater, except in two studies which reported values of 64.8% [17] and 16.7%. [16] Specificity ranged from 57.1% to 94.3%. [16, 17] Positive predictive values ranged from to 38.0% to 86.7%, [17, 23] and negative predictive values from 54.5% to 93.2%. [21, 23] Two studies derived predictive ability from the dual-task 'cost', [11, 14] which was defined as the difference in performance between the single and dual-task test.

Only three studies provided statistical measures for the fall prediction of the single task and the dual-task individually. [16, 17, 21] Increased walking time during single and dual-task conditions were similarly associated with risk of falling, OR= 1.1 (95% CI, 1.0-1.2) and OR= 1.1 (95% CI, 0.9-1.1), respectively. [17] Variation in stride time also predicted falls, OR= 13.3 (95% CI, 1.6-113.6) and OR= 8.6 (95% CI, 1.9-39.6) in the single and dual-task conditions respectively. [21] Walking speed predicted recurrent falls during single and dual-tasks, OR = 0.96 (95% CI, 0.94-0.99) and OR= 0.60 (95% CI, 0.41-0.85), respectively. [16] The later study reported that a decrease in walking speed increased risk of recurrent falls by 1.67 in the dual-task test compared to 1.04 during single-task. All values given in these three studies, for both single and dual-task tests, were interpreted as significant in predicting falls by their respective authors.

Discussion

Only three prospective studies directly compared the individual predictive values of the single and dual-task tests. The first such study concluded that the dual-task test was in fact equivalent to the single-task test in predicting falls. [17] This particular study also reported the lowest positive predictive value of all dual-task tests at 38%. The second study [21] also reported similar predictive values for the single and dual-task assessments, as well as a relatively low positive predictive value of 53.9%. Given that all other studies reported higher predictive values, it may be postulated that at the very least, dual-task tests are comparable to single-task tests in predicting falls. Furthermore, the two studies focused on subjects from senior housing facilities and hospital inpatients (187 and 57 participants respectively), and therefore results may not represent all elderly community-dwelling individuals. The third study [16] concluded that subjects who walked slower during the single-task assessment would be 1.04 times more likely to experience recurrent falls than subjects who walked faster. However, after a poor performance in the dual-task assessment, their risk may be increased to 1.67. This suggests that the dual-task assessment can offer a more accurate figure on risk of falling. Again, participants tested in this study were recruited from senior housing facilities, and thus results may not be directly applicable to the community-dwelling older adult.

Eight studies focused on community-dwelling participants, and all but one [20] suggested that dual-task performance was associated with falls. Evidence that dual-task assessments may be more suitable for fall prediction in the elderly who are healthier and/or living in the community as opposed to those with poorer health is provided by Yamada *et al.* [11] Participants were subdivided into groups by results of a Timed Up & Go test, separating the 'frail' from the 'robust'. It was found that the dual-task assessments were associated with falls only in groups with a higher functional capacity. This intra-cohort variability may account for, at least in part, why three studies included in this review concluded that there was no benefit in performing dual-task assessments. [17, 20, 25] These findings conflicted with the remaining thirteen studies and may be justified by one or all of several possible reasons: (1) the heterogeneity of the studies, (2) the non-standardised application of the dual-task paradigm, or (3) the hypothesis that dual-task assessments are more applicable to specific subpopulations within the generalised group of 'older adults', or further, that certain primary and secondary task combinations must be used to produce favourable results.

The heterogeneity among the identified studies played a major role in limiting the scope of analysis and potential conclusions derived from this review. For example, the dichotomisation of the community-dwelling participants in to frail versus robust [11] illustrates the variability within a supposedly homogenous patient population. Another contributor to the heterogeneity of the studies is the broad range of cognitive or secondary tasks used, which varied between manual tasks [19] and simple or complex cognitive tasks. [10-21, 23-25] The purpose of the secondary task is to reduce attention allocated to the primary task. [5] Since the studies varied in secondary task(s) used, each with a slightly different level of complexity, attentional resources redirected away from the primary balance or gait task would also be varied. Hence, the ability of each study to predict falls is expected to be unique, or poorer, in studies employing a secondary task which is not sufficiently challenging. [26] One important outcome from this review has been to highlight the lack of a standardised protocol for performing dual-task assessments. There is currently no identified combination of a primary and secondary task which has proven superiority in predicting falls. Variation in the task combinations, as well as varied participant instructions given prior to the completion of tasks, is a possible explanation for the disparity between results. To improve result consistency and comparability in this emerging area of research, [6] dual-task assessments should be comprised of a standardised primary and secondary task.

Sixteen studies were deemed appropriate for inclusion in this systematic review. Despite a thorough search strategy, it is possible that some relevant studies may have been overlooked. Based on limited data from 2006 to 2011, the exact benefit of dual-task assessments in predicting falls compared to single-task assessments remains uncertain. For a more comprehensive verdict, further analysis is required to combine previous systematic reviews, [7, 8] which incorporates data prior to 2006. Future dual-task studies should focus on fall prediction and report predictive values for both the single-task and the dual-task individually in order to allow for comparisons to be made. Such studies should also incorporate large sample sizes, and assess living conditions and health status of participants. Emphasis on the predictive value of dual-task assessments requires these studies to be prospective in design, as prospective collection of fall data is considered the gold standard. [27]

Conclusion

Due to the heterogeneous nature of the study population, the limited statistical analysis and a lack of direct comparison between single-task and dual-task assessments, the question of whether dual-task assessments are superior to single-task assessments for fall prediction remains unanswered. This systematic review has highlighted significant variability in study population and design that should be taken into account when conducting further research. Standardisation of dual-task assessment protocols and further investigation and characterisation of sub-populations where dual-task assessments may offer particular benefit are suggested. Future research could focus on different task combinations in order to identify which permutations provide the greatest predictive power. Translation into routine clinical practice will require development of reproducible dual-task assessments that can be performed easily on older individuals and have validated accuracy in predicting future falls. Ultimately, incorporation of dual-task assessments into clinical fall prevention programs should aim to provide a sensitive and specific measure of effectiveness and to reduce the incidence, morbidity and mortality associated with falls.

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Conflict of interest

None declared.

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References

[1] Berg WP, Alessio HM, Mills EM, Tong C. Circumstances and consequences of falls in independent community-dwelling older adults. Age Ageing. 1997 Jul;26(4):261-8.

[2] Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing. 2006 Sep;35 Suppl 2:ii37-ii41.

[3] Lord SR, Menz HB, Tiedemann A. A physiological profile approach to falls risk assessment and prevention. Phys Ther. 2003;83(3):237.

[4] Yogev-Seligmann G, Hausdorff JM, Giladi N. The role of executive function and attention in gait. Movement Disord. 2008;23(3):329-42.

[5] Pashler H. Dual-task interference in simple tasks: Data and theory. Psychol Bull. 1994;116(2):220.

[6] Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture. 2002;16(1):1-14.

[7] Zijlstra A, Ufkes T, Skelton DA, Lundin-Olsson L, Zijlstra W. Do dual tasks have an added value over single tasks for balance assessment in fall prevention programs? A mini-review. Gerontology. 2008;54(1):40-9.

[8] Beauchet O, Annweiler C, Dubost V, Allali G, Kressig R, Bridenbaugh S, *et al.* Stops walking when talking: a predictor of falls in older adults? Eur J Neurol. 2009;16(7):786-95.

[9] Moe Nilssen R, Nordin E, Lundin Olsson L. Criteria for evaluation of measurement properties of clinical balance measures for use in fall prevention studies. J Eval Clin Pract. 2008;14(2):236-40.

[10] Siu KC, Lugade V, Chou LS, van Donkelaar P, Woollacott MH. Dual-task interference during obstacle clearance in healthy and balance-impaired older adults. Aging-Clin Exp Res. 2008 Aug;20(4):349-54.

[11] Yamada M, Aoyama T, Arai H, Nagai K, Tanaka B, Uemura K, *et al.* Dual-task walk is a reliable predictor of falls in robust elderly adults. J Am Geriatr Soc. 2011 Jan;59(1):163-4.

[12] Faulkner KA, Redfern MS, Cauley JA, Landsittel DP, Studenski SA, Rosano C, *et al.* Multitasking: association between poorer performance and a history of recurrent falls. J Am Geriatr Soc. 2007 Apr;55(4):570-6.

[13] Melzer I, Kurz I, Shahar D, Levi M, Oddsson L. Application of the voluntary step execution test to identify elderly fallers. Age Ageing. 2007 Sep;36(5):532-7.

[14] Nordin E, Moe-Nilssen R, Ramnemark A, Lundin-Olsson L. Changes in step-width during dual-task walking predicts falls. Gait Posture. 2010 May;32(1):92-7.

[15] Herman T, Mirelman A, Giladi N, Schweiger A, Hausdorff JM. Executive control deficits as a prodrome to falls in healthy older adults: a prospective study linking thinking, walking, and falling. J Gerontol A-Biol. 2010 Oct;65(10):1086-92.

[16] Beauchet O, Annweiler C, Allali G, Berrut G, Herrmann FR, Dubost V. Recurrent falls and dual task-related decrease in walking speed: is there a relationship? J Am Geriatr Soc. 2008 Jul;56(7):1265-9.

[17] Beauchet O, Allali G, Annweiler C, Berrut G, Maarouf N, Herrmann FR, *et al.* Does change in gait while counting backward predict the occurrence of a first fall in older adults? Gerontology. 2008;54(4):217-23.

[18] Beauchet O, Dubost V, Allali G, Gonthier R, Hermann FR, Kressig RW. 'Faster counting while walking' as a predictor of falls in older adults. Age Ageing. 2007 Jul;36(4):418-23.

[19] Toulotte C, Thevenon A, Watelain E, Fabre C. Identification of healthy elderly fallers and non-fallers by gait analysis under dual-task conditions. Clin Rehabil. 2006 Mar;20(3):269-76.

[20] Vaillant J, Martigne P, Vuillerme N, Caillat-Miousse JL, Parisot J, Juvin R, *et al.* [Prediction of falls with performance on Timed "Up-and-Go" and one-leg-balance tests and additional cognitive tasks]. Ann Readapt Med Phys. 2006 Feb;49(1):1-7.

[21] Kressig RW, Herrmann FR, Grandjean R, Michel J-P, Beauchet O. Gait variability while dual-tasking: fall predictor in older inpatients? Ageing-Clin Exp Res. 2008 Apr;20(2):123-30.

[22] Springer S, Giladi N, Peretz C, Yogev G, Simon ES, Hausdorff JM. Dual-tasking effects on gait variability: the role of aging, falls, and executive function. Movement Disord. 2006 Jul;21(7):950-7.

[23] Lindemann U, Nicolai S, Beische D, Becker C, Srulijes K, Dietzel E, *et al.* Clinical and dual-tasking aspects in frequent and infrequent fallers with progressive supranuclear palsy. Movement Disord. 2010 Jun 15;25(8):1040-6.

[24] Hyndman D, Ashburn A, Yardley L, Stack E. Interference between balance, gait and cognitive task performance among people with stroke living in the community. Disabil Rehabil. 2006 Jul 15-30;28(13-14):849-56.

[25] McCulloch KL, Buxton E, Hackney J, Lowers S. Balance, attention, and dual-task performance during walking after brain injury: associations with falls history. J Head Trauma Rehab. 2010 May-Jun;25(3):155-63.

[26] Verghese J, Buschke H, Viola L, Katz M, Hall C, Kuslansky G, *et al.* Validity of divided attention tasks in predicting falls in older individuals: a preliminary study. J Am Geriatr Soc. 2002;50(9):1572-6.

[27] Lamb SE, Jørstad Stein EC, Hauer K, Becker C. Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. J Am Geriatr Soc. 2005;53(9):1618-22.