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The effect of the motor dual-task on static and dynamic postural control and classification of the motor task difficulty - Systematic Review

El efecto de la tarea motora dual sobre el control postural estático y dinámico y la clasificación de la dificultad de la tarea motora - Revisión sistemática

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Abstract. Many daily activities require performing multiple tasks and involve the integration of cognitive and motor skills, on which the outcome depends. Many studies approach the influence of cognitive tasks on gait and postural control, but few studies analyze the effect of another motor task during gait or postural control. This review aims to analyze the motor tasks used in motor dual-tasks studies and classify motor tasks as to their difficulty level. The literature review was conducted according to PRISMA guidelines in the databases: Medline, Web on Science, and Scopus during December 2019, using the key-words: motor dual-task, secondary motor task, gait, and postural control. It included observational studies based on the effects of motor dual-tasking in static and dynamic postural control, published in the last ten years. N = 215 studies were found within the databases, and this review included sixteen studies. One study analyzed gait with secondary motor task of different levels of complexity. Three studies analyzed the primary motor task (gait) at different difficulty levels or conditions. They all found that more complex tasks lead to poorer gait performance.In conclusion, a classification of the motor tasks is suggested according to their complexity level and suggests the need for more studies with motor tasks of different levels of difficulty. The static and dynamic postural control parameters analyzed in this review were negatively affected compared to the simple motor task, regardless of age or clinical condition.

Key-words: motor dual-task, motor task difficulty, gait, postural control

Resumen. Muchas actividades diarias requieren múltiples tareas e implican la integración de habilidades cognitivas y motoras, de las cuales depende el resultado. Muchos estudios abordan la influencia de las tareas cognitivas en la marcha y el control postural, pero pocos estudios analizan el efecto de otra tarea motora durante la marcha o el control postural. Esta revisión tiene como objetivo analizar las tareas motoras utilizadas en los estudios de duales tareas motoras y clasificar las tareas motoras en función de su nivel de dificultad. La revisión de la literatura se realizó de acuerdo con las guias de PRISMA en las bases de datos: Medline, Web on Science y Scopus durante diciembre de 2019, utilizando las palabras clave: tarea motora dual, tarea motora secundaria, marcha y control postural. Incluyó estudios observacionales basados en los efectos de la tarea motora dual en el control postural estático y dinámico, publicados en los últimos diez años. N = 215 estudios se encontraron dentro de las bases de datos, y dieciséis estudios se incluyeron en esta revisión. Un estudio analizó la marcha con una tarea motora secundaria de diferentes niveles de complejidad y tres estudios analizaron la tarea motora primaria (marcha) en diferentes niveles de dificultad o condiciones y todos encontraron que las tareas más complejas conducen a un rendimiento de la marcha más pobre. En conclusión, se sugiere una clasificación de las tareas motoras según su nivel de complejidad y sugiriendo la necesidad de más estudios con tareas motoras de diferentes niveles de dificultad. Los parámetros de control postural estáticos y dinámicos analizados en esta revisión se vieron afectados negativamente en comparación con la tarea motora simple, independientemente de la edad o la condición clínica.

Palabras clave: tarea motora dual, tarea motora dificil, marcha, control postural.

Introduction

Postural control (PC) depends on a complex interaction between the neural and musculoskeletal systems (Huang & Mercer, 2001). An efficient PC is fundamental to the success of most daily tasks. Gait involves bilaterally coordinated limb movements and maintenance of dynamic postural control. People with motor impairment, cognitive decline, or both, have more gait changes in dual-task activities (Woollacott & Shumway-Cook, 2002; Yogev et al., 2008).

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The relationship between attention and PC is a developing area of study that has revealed important aspects of the cognitive processing role in PC. The most used methodology to ascertain its relationship is the Dual-Task (DT) paradigm, in which the PC, considered a primary task, and a secondary task, are performed simultaneously (Woollacott & Shumway-Cook, 2002).

The ability to perform a second task while a first one is executed is crucial in most daily activities, especially when some motor act is involved, as a poor gait performance in dual-task can result in a fall (Beauchet et al., 2009).

The attentional demands of a task and the interference effects of concurrent tasks could be influenced by several factors, such as age, skill level, and the nature of the tasks involved (Huang & Mercer, 2001).

The brain's ability to organize multi-task interactions is essential to motor control and balance (Plummer et al., 2013). Dual-Task Cost (DTC) occurs when the simultaneous performance of two different tasks results in performance deterioration (Beurskens et al., 2016; Plummer & Eskes, 2015). It is calculated as the percentage of performance decrements in dual-task relative to the single-task.

Some studies assess task performance using the task prioritization concept, in which it is usually assumed that task prioritization can be obtained by means of an external priority instruction on the importance of each task (Plummer & Eskes, 2015). Other authors impose a focus of attention during the task performed and conclude that the focus of attention on the cognitive task while performing the dual-task can favor motor learning (Arce-Cifuente et al., 2020).

Preserving balance during dual-tasks or multi-tasks is a complex outcome of trunk stability and the sensory-motor and automatic central functions. Therefore, executing simultaneously two tasks demands a higher level of attention, balancing ability, and executive function than a single task performance (Plummer et al., 2013).

The postural control and the motor or cognitive tasks occur at the cortical level, enabling one activity interferes with the other or lead to a reduction in automation (Leone et al., 2017).

There are three theories commonly used to explain the dual-task interference. The capacity sharing, when people share processing capacity or mental resources among tasks. This results in lower capacity for each task, and so the performance of at least one task will be impaired. The other theory is the bottlenecks, task switching, it exists a deterioration in the performance of one or both tasks resulting from serial processing when the two tasks need the same neural processor or networks. The last theory is the cross-talk, where the outcome of the processing required for one task conflicts with the processing required for another task (Pashler, 1994).

Several studies, included in a systematic review, showed that different cognitive tasks (e.g., working memory, reaction time, etc.) when performed simultaneously during gait (DT), caused impairments in spatio-temporal gait parameters, such as decreased gait speed, compared to the single-task (only gait) (Al-Yahya et al., 2011). Other studies showed worst results on gait performance under dual-task conditions when the individuals performed a second motor task as transfer coins (O´Shea et al., 2002) or carry a tray (Bond & Morris, 2000). Thus, walking while simultaneously performing a cognitive or motor task negatively affects the individual's gait performance.

Regarding task difficulty, few studies have simultaneously analyzed the population's complexity of postural or gait and other motor tasks. For that reason, we based the analysis of the task's difficulty level on the taxonomy model (McIsaac et al., 2015) and in the classification of the studies included in this review.

There is an ambiguity about the terms task complexity and task difficulty. For some authors, task complexity is a component of difficulty, for others, they are separate concepts. Generally, task difficulty refers to performers experiencing difficulty in executing the task. On the other hand, task complexity can be defined as a result of the interaction between task and performer characteristics, such as the number of task components, concentration, cognitive and physical demands, time pressure, or novelty (Liu & Li, 2012).

Although the amount of research on postural control and dual-tasks has increased in recent years, there are still not many studies that clarify the effect of the difficulty of the static or dynamic postural control tasks on dual-task performance. Besides that, several studies have focused on the effect of the cognitive task component on dual-task. It is challenging to establish conclusions about the influence between concurrent motor and cognitive tasks on postural control, because the studies use different types of tasks, and motor or cognitive tasks performing can require different cognitive resources and motor control (Bayot et al., 2018).

For this reason, the main objective of this review is to analyze the motor tasks used in motor dual-task studies, to classify them as to their level of difficulty, and to determine the effects of task difficulty, both secondary motor tasks and static or dynamic postural control, on dual-task performance.

Methods

This review was conducted according to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement (Moher et al., 2009) and followed the PICOS criteria described in PRISMA (population: humans; intervention: dual-task to evaluate static and dynamic postural control; comparison: none; outcomes: motor dual-task and motor task difficulty to study static and dynamic postural control; study design: all quantitative and qualitative studies in the last ten years).

Data sources and search strategy

The study was conducted independently by two reviewers in the databases: Medline, Web on Science, and Scopus, during December 2019. The search terms used were gait, walking, locomotion, dual-task, multi-task, secondary task, motor dual-task, postural control, postural balance, postural sway, and their combination with 'and' or 'or'. The combination of keywords and MeSH (Medical Subject Headings) terms were also adapted to each database. Screening of titles and abstracts to determine if the study meets any of the exclusion criteria was performed. The inclusion criteria for the studies were as follows:

i. English language;
ii. Published in the last ten years;
iii. Observational (cohort study) studies;
iv. Studies that analyze the effects of motor tasks in static and dynamic postural control in healthy and ill subjects.

Other design studies and the following criteria were excluded:

i. Articles based only on the effect of cognitive tasks on postural control and/or on dual-task training;
ii. Studies in which the primary task is not postural control;
iii. Studies with quality lower than four in the Newcastle-Ottawa Scale.

The studies that fulfilled all eligibility criteria were evaluated in full-text and included in the systematic review (Figure 1). The authors independently assessed the eligibility and methodological quality of the included studies. In the event of disagreement, a decision was taken by consensus.

Data extraction

Upon selection for review, the following data were extracted from each article: author, date of publication, sample characteristics, the aim of the study, study methodology (tasks and outcome measures), and results.

Assessment quality of studies and risk of bias

The methodological quality of observational studies was assessed with the Newcastle-Ottawa Scale. It uses three elements to evaluate the risk of bias in prospective studies: 1) selection of participants (four items: representativeness of the exposed cohort, selection of the non-exposed cohort, ascertainment of the exposure, and demonstration that the outcome of interest was not present at the start of the study); 2) comparability (one item: comparability of cohorts based on the design of the analysis) and 3) outcomes (three items: adequate assessment of outcome, adequate follow-up time, and adequacy of follow-up). A study can be awarded a maximum of 1 point (star) for each numbered item within the selection and outcome categories and a maximum of two points can be given for the comparability category. The maximum score on the Newcastle-Ottawa Scale is 9 (highest quality) (Wells et al., 2019).

The primary reviewer carried out a blinded rating of the methodological quality of the studies, and the second reviewer assessed the methodology quality unblinded. Ambiguous issues were discussed between reviewers, and a consensus was reached.

Result

Figure 1 depicts each step's selection, eligibility, inclusion, and the number of studies. Database searches resulted in 215 papers, of which 16 were duplicates. Then, of the 199 papers, 138 articles were excluded based on the title and abstract screening during the selection process. The remaining 61 articles were thoroughly examined, and 45 were discarded as the task type did not include motor tasks. After these steps, 16 studies have been included in this review.

The 16 studies were analytic observational studies (prospective cohort studies). The quality of observational studies (cohort studies) is moderate based on the Newcastle-Ottawa Scale (Table 1). Data from the included studies are summarized in Table 2.

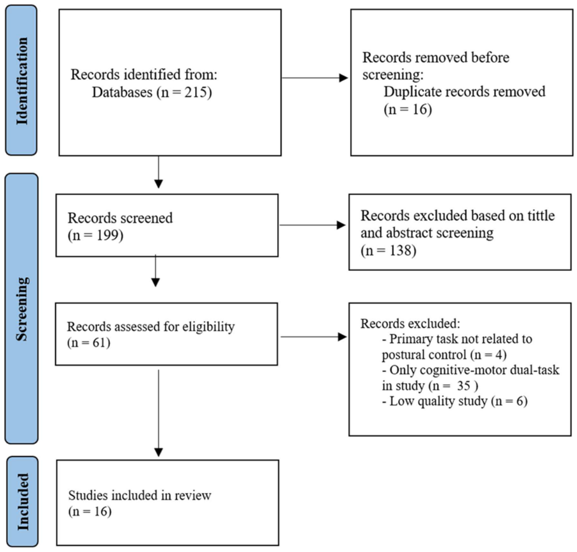

Fig.1. Fluxogram of articles included in the review according to PRISMA

Table 1.
Quality of observational studies based on Newcastle-Ottawa Scale (legend: *=present (1 point) Total Score = 9 points)

Study	Selection	Comparability	Outcome	Total
Nordin et al. (2010)	**	*	*	4
Beurskens & Bock (2013)	**	*	*	4
Makizako et al. (2013)	***	*	*	5
Oh-Park (2013)	***	**	*	6
Abbruzzese et al. (2014)	**	**	*	5
Asai et al. (2014)	**	*	*	4
Baldan & Elmauer (2015)	**	*	*	4
Tang et al. (2015)	**	*	**	5
Beurskens et al. (2016)	***	*	*	5
Demirci et al. (2016)	**	*	*	4
Freire Junior et al. (2017)	****	*	*	6
Mofateh et al. (2017)	***	*	*	5
Hunter et al. (2018)	***	*	*	5
Liu et al. (2018)	***	*	*	5
Kachouri et al. (2019)	****	*	*	6
Rabaglietti et al. (2019)	****	**	*	7

Sample Characteristics

Most studies used healthy individuals (Beurskens et al., 2016; Abbruzzese et al., 2014; Asai et al., 2014; Beurskens & Bock, 2013; Makizako et al., 2013; Nordin et al., 2010; Oh-Park et al., 2013; Tang et al., 2015) to analyze postural control in motor dual-tasks. School-age children were compared with young adults (Abbruzzese et al., 2014), young adults with the elderly (Beurskens & Bock, 2013; Makizako et al., 2013; Oh-Park et al., 2013), and older non-fallers with older fallers (Júnior et al., 2017). Only six studies report to clinical conditions, namely Sclerosis Multiple (Mofateh et al., 2017), Stroke (Baldan & Elmauer, 2015; Liu et al., 2018), Ataxia (Demirci et al., 2016), Mild Cognitive Impairment (Hunter et al., 2018), and children with intellectual disability (Kachouri et al., 2019). Five studies use a sample type not making comparisons between groups (Beurskens et al., 2016; Asai et al., 2014; Nordin et al., 2010; Tang et al., 2015; Liu et al., 2018). One study examined the effect of a secondary motor task on walking ability in childhood (Rabaglietti et al., 2019).

Description of motor tasks

In most studies, the principal motor task analyzed was gait (Beurskens et al., 2016; Abbruzzese et al., 2014; Asai et al., 2014; Beurskens & Bock, 2013; Nordin et al., 2010; Oh-Park et al., 2013; Júnior et al., 2017; Mofateh et al., 2017; Baldan & Elmauer, 2015; Liu et al., 2018; Hunter et al., 2018; Kachouri et al., 2019; Rabaglietti et al., 2019).

Only three studies analyzed static and/or dynamic balance as principal motor task (e.g. standing Romberg stance under foam surface; Tandem Stance; Time Up and Go) (Makizako et al., 2013; Tang et al., 2015; Demirci et al., 2016).

The secondary motor tasks used were gross motor tasks, e.g. holding a tray (Abbruzzese et al., 2014; Nordin et al., 2010; Oh-Park et al., 2013) or a cup (Makizako et al., 2013; Tang et al., 2015; Kachouri et al., 2019; Rabaglietti et al., 2019) or fine motor tasks (e.g. buttoning a button (Beurskens & Bock, 2013; Demirci et al., 2016), opening and closing a bag zipper (Demirci et al., 2016), transferring a coin from one pocket to the other (Júnior et al., 2017).

Most studies (Makizako et al., 2013; Nordin et al., 2010; Oh-Park et al., 2013; Tang et al., 2015; Mofateh et al., 2017; Hunter et al., 2018; Kachouri et al., 2019; Rabaglietti et al., 2019) used carrying cups and/or a tray as the secondary motor task. Baldan & Elmauer (2015) and Demirci et al. (2016) used the task of transferring a ball from one hand to another as a secondary motor task.

Only the study by Abbruzzese et al. (2014) analyzed gait with secondary motor tasks of different levels of complexity (simple motor task: 'Holding an empty tray with both hands', 'Holding an empty pitcher with one hand'; complex motor task: 'Holding a tray with an unsecured empty cup on top with both hands', 'Holding a pitcher with a cup of water secured inside with one hand'; simple dual-task: 'Gait and Empty tray, held with two hands', 'Gait and Pitcher with empty cup secured inside, held with one hand by the handle'; complex dual-task: 'Gait and Tray with unsecured empty cup on top, held with two hands', 'Gait and Pitcher with cup of water secured inside, held with one hand by the handle') and the study by Oh-Park et al. (2013) of task prioritization in motor dual-task (walk and holding a tray with instructions to focus attention on keeping the tray as steady as possible; walk and holding a tray focusing attention on walking at preferred pace).

Three studies analyzed the primary motor task at different levels of difficulty: gait in four different velocities (self-selected comfortable velocity, very slow, slow, and fast) (Asai et al., 2014), walking in four different conditions (wide path and preferred pace, narrow path and preferred pace, wide path and fast pace, obstacles wide path and preferred pace) (Beurskens & Bock, 2013), and three different velocity conditions of gait (slow, normal and fast) (Nordin et al., 2010).

Dual-task outcome measures

The gait variables most analyzed in the motor dual-tasks were gait speed, cadence, stride length, stride width, percent of time in the double support phase, through GAITRite® System (Abbruzzese et al., 2014; Nordin et al., 2010; Oh-Park et al., 2013; Júnior et al., 2017; Liu et al., 2018; Hunter et al., 2018), MTx® System (Beurskens & Bock, 2013), Qualisys® System (Mofateh et al., 2017) or analytical formulas (Asai et al., 2014; Baldan & Elmauer, 2015).

Balance Evaluation-Systems Test (Júnior et al., 2017), Ten Meter Walking Test (TMWT), and the Timed Up and Go Test (TUGT) (Kachouri et al., 2019) were methodologies also used to analyze gait performance.

Static and dynamic balance in one of the studies was analyzed through clinical trial tests such as Single Leg Stance Time; Tandem Stance Time; Four Square Step Test; 360° Degrees of Rotation Time; TUGT completing time (Demirci et al., 2016). In another study, which evaluated balance in motor dual-tasks, the variable analyzed was anterior-posterior sway through triaxial accelerometry (Makizako et al., 2013). This study also analyzed the electromyography of the tibialis anterior and medial gastrocnemius ankle muscles.

In one of the studies, the TUGT performance was analyzed in a single TUGT task and motor dual-task (TUGT while carrying a cup of water) (Tang et al., 2015).

Table 2.
Results of motor tasks in static and dynamic postural control.

Authors (year)	Sample Characteristics (n; mean±SD)	Aim of the study	Methodology Primary Motor Task	Outcome Primary Motor Task	Secondary Motor Task	Outcome Secondary Motor Task	Motor Dual Task Dual Task	Outcome	Task duration	Number of trials	Results
Abbruzzese et al. (2014)	School-aged children: n=10 (8.1±1.2 years). Healthy young adults: n=10 (26.8±4.9 years).	To analyze the effects of complexity, type of task, and age on the ability to walk while performing concurrent manual tasks between school-aged children and young adults.	Gait	GAITRite® Gait velocity, Cadence, Stride length, Base of support, Percent time in double limb support.	Holding an empty pitcher with one hand (SP); Holding an empty tray with both hands (ST); Holding a pitcher with a cup of water secured inside with one hand (CP); Holding a tray with an unsecured empty cup on top with both hands (CT).	ND	Gait+SP Gait+ST Gait+CP Gait+CT	GAITRite® Gait velocity, Cadence, Stride length, Base of support, Percent time in double limb support.	4.6m	3 trials under each DT	The children had a more variable step length and step time than adults in all walking conditions. Gait variability is greater in the most complex motor tasks.
Asai et al. (2014)	Healthy older people: n=117 (73.7±4.0 years)	To assess trunk movements during cognitive-task gait and manual-task gait.	Gait in 4 speeds: Self-selected comfortable, Very slow, Slow, Fast.	Triaxial accelerometers: STV RMS in the ML direction RMS in the AP direction Arithmetic formulas: Gait speed	To carry a ball on a tray.	ND	Gait in self-selected comfortable speed +Carrying a ball on a tray.	Triaxial accelerometers: STV RMS in the ML direction RMS in the AP direction Arithmetic formulas: Gait speed	Gait during 10m.	1	The trunk oscillation was lower in the motor DT than in the simple gait task.
Baldan & Elmauer (2015)	Adults with stroke: n=12 (56.5±26.92 years). Healthy adults: n=12 (52.33±7.58 years)	To analyze and compare performing DT effect on gait in subjects with stroke and healthy adults.	Gait	Evaluated through arithmetic formulas: Step length, Cadence, Average speed.	To transfer a ball from one hand to another.	ND	Gait+To transfer a ball from one hand to another	Evaluated through arithmetic formulas: Step length, Cadence, Average speed.	Gait during 10m.	3 trials under each DT	The group of adults with stroke had worse motor DT performance than simple task (gait).
Beurskens et al. (2016)	Young adults: n=12 (23.8±2.8 years)	To examine the role of different secondary task demands on gait in young adults and assess the associated neural activation patterns.	Gait	OptoGait-System (10m): Gait velocity; Stride length; Stride time	Held two sticks with a ring at the end, one in each hand.	Total time of contact between the two interconnected rings	Gait+Held two sticks with a ring at the end,	OptoGait-System: Gait velocity; Stride length; Stride time Mobile EEG system: Neural Correlates	2min	1	The motor task affected walking performance in young adults: reduced gait velocity and stride length, increased stride time.
Beurskens & Bock (2013)	Young people: n=15 (21.7±1.2 years) Older people: n=15 (70.5±6.4 years)	To evaluate whether the difficulty of the walking task matters.	Walking along a straight pathway of 20m length in 4 different conditions: 1:Wide path and preferred pace; 2:Narrow path and preferred pace; 3.Wide path and fast pace; 4.Obstacles wide path and preferred pace.	MTx® Evaluated for each step cycle of the lower right leg: Step duration, Step cycles, Step consistency. Gait Speed	Task check (20s) Task button (20s)	Checking speed: number of checked boxes per second. Buttoning speed: number of fixed buttons per second.	Wide+check Narrow+ check Obstacles+ check Wide Fast+check Wide+button Narrow+ button Obstacles+ button Wide Fast+button	MTx® Evaluated for each step cycle of the lower right leg: step duration, step cycles, step consistency. Gait Speed	Gait during 20m	2 trials under each DT	In older people changes in gait pattern is more pronounced in the task check because it needs to be controlled while walking.
Demirci et al. (2016)	Patients with ataxia: n=25 Healthy subjects: n=25	To analyze the effect of motor and cognitive tasks on clinical balance	Single-Leg Stance Time Tandem Stance time 360° Degrees of	Static and Dynamic Balance	Taking 3 objects from the bag respectively (money, the keys, pencil) and putting them back	ND	SLST+ Taking 3 objects from the bag respectively (money, the keys,	Static and Dynamic Balance	ND	ND	4SST was completed in a longer time in ataxic group when performed with motor task. Motor task deficits

		performance of patients with ataxia, by using practical clinical tests.	Rotation Time Timed up and go test completing time Four Square Step Test		in turn Carrying a glass on tray Opening and closing bag zipper Transferring the ball from one hand to the other Buttoning up the shirt button		pencil) and putting them back in turn. TST+ Carrying a glass on a tray. 360 DRT+ Transferring the ball from one hand to the other TUG completing time+Opening and closing bag zipper 4SST+ Buttoning up the shirt button				were more obvious than cognitive task deficits in 4SST.
Freire Junior et al. (2017)	Older people: non-fallers: n=35 (67.97±4.82 years) fallers: n=27 (67.96±5.7 years)	To evaluate the biomechanical aspects of DT gait in older fallers and non-fallers.	Gait	GAITRite®: Gait speed, Cadence, Stride time, Step length, Single support, Stride time variability BESTest: Functional balance	Transferring a coin from one pocket to the other	ND	Walking+ Transferring a coin from one pocket to the other	GAITRite®: Gait speed, Cadence, Stride time, Step length, Single support, Stride time variability BESTest: Functional balance Dual-task cost	8 m	3	During DT was found slower speed and cadence, shorter step length, longer stride time and single support time, and increased variability compared to single task (gait).
Hunter et al. (2018)	People with MCI: n=41 (76.20±7.65 years) Control group: n=41 (72.10±3.80 years)	To create a framework for task complexity of concurrent motor and cognitive tasks with gait in people with MCI.	Gait	GAITRite® Gait velocity	Carrying a glass of water on a tray with one hand.	ND	Gait+Carrying a glass of water on a tray with one hand.	GAITRite® Gait velocity	ND	ND	Gait velocity decreased for both groups with the addition of the motor and cognitive tasks singly.
Kachouri et al. (2019)	Children with intellectual disability: n=15 (8.6±1.42 years) Control group: n=15 (8.87±1.72 years)	To assess the effects of dual-task on walking performance.	Gait	Ten Meter Walking Test (TMWT) and the Timed Up and Go Test (TUGT)	Carrying a glass of water	ND	TUGT+ Carrying a glass of water TMWT+ Carrying a glass of water	Ten Meter Walking Test (TMWT) and the Timed Up and Go Test (TUGT) Poured water was recorded.	Time complete the trial (TUGT and TUGT)	3	DT walking decrements were significantly higher when performing a concurrent motor task than cognitive only.
Liu et al. (2018)	Individuals with Stroke: n=23 (51.5±10.5 years)	To investigate the effects of cognitive and motor DT on gait performance and brain activities in stroke	Gait	GAITRite®: Speed (cm/s); Cadence (steps/min); Stride time (s); Stride length (cm).	Carrying a tray with a bottle of water.	ND	Walking+ With unaffected hand carrying a tray with a bottle of water.	GAITRite®: Speed (cm/s); Cadence (steps/min); Stride time (s); Stride length (cm).	60 s	2	Gait performance deteriorated during cognitive and motor DT and there was no significant difference between these two DT types in individuals with stroke.
Makizako et al. (2013)	Healthy younger adults: n=30 (22.2±1.5 years) Healthy older adults: n=27 (71.3±3.4 years)	To study age-related differences in the influence of cognitive task performance on postural sway and muscle activity on unstable balance conditions.	Standing with feet close together (Romberg stance) on a compliant foam surface with a glass full of sand in the left hand.	Anterior-posterior sway (triaxial accelerometer MA3-04Ac, Micro Stone Inc) EMG activity (SX230, Biometrics Ltd) of the ankle musculature (tibialis anterior and medial gastrocnemius of the right leg)	Holding a glass of water in the left hand.	ND	Standing on a compliant foam surface in the Romberg stance+ Holding a glass of water in the left hand.	Anterior-posterior sway (triaxial accelerometer MA3-04Ac, Micro Stone Inc) EMG activity (SX230, Biometrics Ltd) of the ankle Musculature (tibialis anterior and medial gastrocnemius of the right leg)	40 s	10 (5 trials*2 sessions)	Younger and older adults exhibited longer RTs under dual-cognitive compared to control and motor DT conditions.
Mofateh et al. (2017)	MS patients with fall history: n=25 MS patients without fall history: n=25 Healthy controls: n=25	To compare the effects of cognitive or motor tasks on gait performance between healthy	Gait in treadmill	Qualisys Inc., Sweden: Cadence, Stride length, Step width, Swing time. Treadmill (BiometrixTM)	Carrying a tray with glasses.	ND	Walking+ Carrying a tray with glasses.	Qualisys Inc., Sweden: Cadence, Stride length, Step width, Swing time. Treadmill (BiometrixTM)	2 min and 5 min rest	3 trials for each DT	In all participants, performing a concurrent cognitive task markedly altered gait parameters compared to a concurrent motor

Nordin et al. (2010)	Older people: n=230	To evaluate whether gait pattern changes between single and DT conditions were associated with risk of falling in older people.	Gait in 3 velocity conditions: Slow, Normal, Fast.	GAITRite® Step-length, Step-width, Step-time, Double-support-time, Gait speed.	Cup (a saucer with a coffee-cup) Tray (a rectangular wooden tray) Tray-Cup (the tray with the saucer and cup on top)	ND	Walking+ Carry a cup in one hand Walking+ Carry a tray using both hands Walking+ Carry a tray with the filled cup using both hands.	GAITRite® Step-length, Step-width, Step-time, Double-support-time, Gait speed.	ND	1 trial for each DT	DTC's were related to the risk of falling in two of the five DT, i.e. the cognitive task ''Count'' and the manual task ''Cup''.
Oh-Park (2013)	Older people: n=16 (74.5±6.4 years) Young individuals: n=18 (19.2±2.7 years)	To analyze the DT effect on subtasks during motor DT under specific instruction of task prioritization in old compared to young adults	Gait	GAITRite® -Gait Velocity, -Stride-to-stride variability	Holding a tray as steady as possible during quiet stance for 10s.	ND	Walk+Holding a tray with instructions to focus attention on keeping the tray as steady as possible Walk+Holding a tray focusing attention on walking at preferred pace	GAITRite® Gait Velocity, Stride-to-stride variability	ND	2 trials for each DT	Compared to young, older adults tend to compromise the task involving upper limbs during motor DT even when instructed to prioritize this task over gait.
Rabaglietti et al. (2019)	Female children: n=53 (10±2 years) Group1: n=17 (7-9 years) Group2:n=36 (10-13 years)	To examine the effect of a secondary motor task on walking ability and whether performance differed according to age in children with typical development.	Gait	Walking test (stopwatch); Gait Speed	Carrying a glass of water; Carrying a ball on a round tray; Carrying a glass of water+a ball on a round tray.	ND	Walking+ Carrying a glass of water; Walking+ Carrying a ball on a round tray; Walking+ Carrying a glass of water and a ball on a round tray.	Walking test (stopwatch); Gait Speed DTC	14m	1 trial for each DT (3 min rest between each task)	Independent of the age, the DT performance might affect walking performance depending on the required secondary task. Exists an association between working memory skills and DTC in walking ability.
Tang et al. (2015)	Community-dwelling middle-aged and older adults: n=65 (71.5±8.1 years)	To investigate whether DT TUG could identify prefrail individuals better than single-task TUG.	TUG	Stopwatch: Time to complete TUG test	Carrying a cup of water	ND	TUG+ Carrying a cup of water	TUG performed	Stopwatch: Time to complete TUG test	3	TUG+carrying a cup of water is more valid and sensitive than single task TUG in identifying prefrail individuals.

Legend: AP: anteroposterior; BESTest: Balance Evaluation – Systems Test; CP: complex pitcher; CT: complex tray; DTC: Dual-Task Cost; ND: no data; MCI: Mild Cognitive Impairment; ML: mediolateral; MS: Multiple Sclerosis; RMS: root-mean-square; rpm: revolutions per minute; RTs: Reaction Times; SLST: Single Leg Stance Time; SP: simple pitcher; ST: simple tray; STV: stride time variability; TST: Tandem Stance Time; TUGT completing time: Timed Up and Go Test completing time; 4SST: Four Square Step Test; 360º DRT: 360º Degrees of Rotation Time.

Discussion

Dual-task paradigms usually are used for two different purposes: to investigate the attentional demands of a motor task and to examine the effects of concurrent cognitive or motor tasks on motor performance (Huang & Mercer, 2001).

In this review, we found that the principal motor task analyzed was the gait (Beurskens et al., 2016; Abbruzzese et al., 2014; Asai et al., 2014; Beurskens & Bock, 2013; Nordin et al., 2010; Oh-Park et al., 2013; Júnior et al., 2017; Mofateh et al., 2017; Baldan & Elmauer, 2015; Liu et al., 2018; Hunter et al., 2018; Kachouri et al., 2019). Most secondary motor tasks refer to gross or fine motor tasks, such as carrying a tray or holding a cup during gait (Makizako et al., 2013; Nordin et al., 2010; Oh-Park et al., 2013; Tang et al., 2015; Mofateh et al., 2017; Hunter et al., 2018; Kachouri et al., 2019), buttoning a button (Beurskens & Bock, 2013; Demirci et al., 2016), opening and closing a bag zipper (Demirci et al., 2016), and transferring a coin from one pocket to the other (Júnior et al., 2017). These secondary motor tasks are tasks commonly used in the natural context of daily life activities.

Samples that include healthy individuals should be homogeneous since when comparing school-age children with young adults or young people with the elderly, there is already a bias due to the physical, psychological, and physiological changes that come from aging. For example, children apply different anticipatory strategies than adults, making last-minute adjustments, while adults plan well ahead of upcoming obstacles (Schott & Klotzbier, 2018), since the level of development and maturation are different.

The Abbruzzese et al. (2014) study verified that children had a more variable step length and step time than adults in all walking conditions. The same was verified in the study of Vallis & McFadyen (2005). The authors found reductions in gait speed and step length in children (9 to 12 years old), only two steps and one step prior to obstacle circumvention, respectively, while adults maintain a constant speed and step length. Cherng, Liang, Hwang & Chen

(2007) showed that young children (4 to 6 years old) decrease their stride length and increase the variability of temporal and spatial gait parameters when walking and carrying a tray with or without marbles on it. Other studies showed children with impaired motor performance when walking in DT situations compared to young adults (Krampe et al., 2011), suggesting that children do not demonstrate adult-like use of sensory information in balance control before 12 years old (Peterson et al., 2005).

Makisako et al. (2013) found that the cognitive task had a more significant impact than the motor task in decreasing lower limb muscle activity and increasing anterior-posterior trunk acceleration during a Romberg stance in older people compared to young adults.

Júnior et al. (2017) showed that walking while transferring coins from one pocket to the other causes a decrease in speed and cadence, shorter step length, longer stride time, and single support time, and increased variability compared to the single-task (gait) in older people.

In clinical conditions, the gait velocity and gait performance in DT were significantly worse than in a concurrent motor task only (Hunter et al., 2018; Kachouri et al., 2019). In addition, both studies (Baldan & Elmauer, 2015; Liu et al., 2018) that assessed the effect of motor dual-task in subjects with stroke also found deteriorating gait performance in motor dual-task compared to single-task (gait). Demirci et al. (2016) showed that the 4SST took greater time to be completed when concurrently performed with a secondary motor task, buttoning up the shirt button, in subjects with ataxia.

These results show that static and dynamic postural control was negatively affected while simultaneously performing a secondary motor task in clinical conditions. Other studies corroborate these results; for example, Marchese et al. (2003) showed that during motor dual-task, motor sequence of thumb opposition to the other fingers during quiet stance, the postural sway deterioration was more evident in subjects with Parkinson´s Disease than in healthy subjects. O´Shea et al. (2002) showed a decline in speed gait when performing another motor task, transferring coins from one pocket to another. Besides that, they decreased the coin transference rate between the standing and walking conditions in subjects with Parkinson´s Disease.

A complex motor task can require more attention and reduce residual attention capacity. In this situation, the competition for attention to perform different tasks is expected to happen (Laessoe et al., 2008). Few studies (Abbruzzese et al., 2014; Asai et al., 2014; Beurskens & Bock, 2013; Nordin et al., 2010) have analyzed the motor tasks' difficulty level. When the task becomes more complex, and walking is challenged, the focus of attention shifts toward the motor task to maintain gait stability. The types of motor tasks used as the concurrent motor task vary across studies (carrying a cup or tray, transferring coins or balls). Each motor task imposes distinct biomechanical constraints on the upper limbs and trunk, which can cause a greater and presumably also different constraint in the gait. Beurskens & Bock (2013) investigated the role of differently challenging walking conditions in DT and showed that the age-related increase of DTC is considerably greater with the visual demand than with the motor task demand, being more evident when walking on a narrow or obstacles path. Nordin et al. (2010) assessed gait with three different velocities and demands motor tasks: carrying a cup in one hand, carrying a tray using both hands, and carrying a tray with the filled cup using both hands. In this last dual-task, none of the gait parameters was related to the risk of falling, suggesting the cup task was more challenging because the other motor tasks did not affect gait and fall risk.

Rabaglietti et al. (2019) suggest that walking performance under a dual-task depends on the difficulty level; they found similar differences in the dual-task performance between children with 7-9 years and 10-13 years. Abbruzzese et al. (2014) found a higher variability in gait in the most complex motor tasks (holding a pitcher with a cup of water secured inside with one hand and holding a tray with an unsecured empty cup on top with both hands) compared to a simple task (holding an empty pitcher with one hand and holding an empty tray with both hands). The dual-task costs related to performing complex motor tasks during walking are higher in school-age children than young and healthy adults. Also, the temporal changes in spatial gait, decreasing gait speed, cadence, step duration and increasing time spent in double support, occurred under simultaneous motor task conditions.

Only Oh-Park et al. (2013) studied task prioritization. They stated that motivation could influence the walking performance while holding a tray with instructions to focus on keeping the tray as steady as possible. They showed that while focusing attention on keeping the tray, gait performance and tray stability were compromised during dual-task compared to single tasks and differed between the age groups. Other studies (Kelly et al., 2010; Remaud et al., 2013; Yogev-Seligmann et al., 2010) have also reported that the instructed focus of attention can affect dual-task performance.

Although the secondary motor tasks and methodologies are heterogeneous, only one study analyzed motor tasks with different complexities (Abbruzzese et al., 2014) and three studies analyzed the primary motor task (gait) in different conditions (Asai et al., 2014; Beurskens & Bock, 2013; Nordin et al., 2010). Then, based on the taxonomy model for classifying motor tasks (McIsaac et al., 2015) and in the single and dual-tasks used in studies of this review, we suggest the classification of motor tasks difficulty level presented in

Table 3.
Classification of motor tasks difficulty level based on the task taxonomy model (McIsaac et al., 2015) and on the motor tasks used in the studies of this review.

Type of task	Task Novelty	Task Complexity	
		Low	High
Single Task	Low	Holding an empty pitcher with one hand. Holding an empty tray with both hands. Carrying a tray with glasses. Taking 3 objects from the bag respectively (money, the keys, pencil) and putting them back in turn. Gait/ walking. Walking wide path and preferred pace.	Holding/Carrying a glass/cup of water. Buttoning a button. Transferring a coin from one pocket to the other. Opening and closing a bag zipper. Carrying a glass of water and a ball on a round tray. Walking wide path and fast pace.
	High	Carrying a ball on a tray. Transferring a ball from one hand to another. Check each box as quickly as possible by an ''X'', using a pen in their dominant hand (task check). TUGT.	Holding a pitcher with a cup of water secured inside with one hand. Holding a tray with an unsecured empty cup on top with both hands. Held two sticks with a ring at the end, one in each hand and the rings were interlocked (not to let the rings touch each other). Standing on a compliant foam surface in the Romberg stance. Execute the SLST. Execute the 360 DRT. Execute the 4SST. Walking with obstacles wide path and preferred pace.
Dual motor-motor	Low	Walking when carrying a cup in one hand. Walking when carrying a glass of water. Walking when holding an empty pitcher with one hand. Walking when holding an empty tray with both hands. Walking when carrying a tray with glasses.	Walking when transferring coins between pockets. Walking when buttoning a button. Walking in a wide path when buttoning a button. Walking and carrying a glass of water and a ball on a round tray.
	High	Walking when carrying a ball on a tray. Walking fast wide path when task check. Walking when transferring a ball from one hand to another. Walking in wide path when task check.	Execute TUG when opening and closing a bag zipper. Execute TUG when carrying a cup of water. Walking when holding a pitcher with cup of water secured inside with one hand. Walking narrow path when check task. Walking obstacles path when check task. Walking narrow path when buttoning a button. Walking obstacles path when buttoning a button. Walking fast wide path when buttoning a button. Walking when holding a tray with an unsecured empty cup on top with both hands. Walking fast when carrying a ball on a tray. Walking when held two sticks with a ring at the end, one in each hand and the rings were interlocked (not to let the rings touch each other). Standing on a compliant foam surface in the Romberg stance when holding a glass of water in the left hand. Execute SLST when taking 3 objects from the bag respectively (money, the keys, pencil) and putting them back in turn. Execute TST when carrying a glass on the tray. Execute 360 DRT when transferring the ball from one hand to the other. Execute 4SST when buttoning up the shirt button.

The concepts of difficulty and complexity of the task are frequently confused. For this reason, in the present review, we adapted the classification McIsaac et al. (2015) suggested, according to the primary or secondary motor single tasks and the motor dual-tasks included in the analyzed studies. Thus, the categorization of complexity and novelty is open to the researcher's interpretation. There can be tasks that do not fit well into the categories of the study by McIsaac et al. (2015). For example, "walking when carrying a glass of water" was classified as a low complex dual-task since Rabaglietti et al. (2019) study was considered a dual-task.

The main limitation of this review was the difficulty in classifying the difficulty or complexity of tasks because it is not easy to standardize. Moreover, as already referred to, the concepts of complexity and difficulty are confused, and many studies do not consider the task's perception of difficulty or novelty by the performer of the task. Furthermore, in this review, few studies analyzed the motor tasks with different difficulty levels, making it difficult to compare and classify the tasks' difficulty levels.

In clinical practice, the use of the dual-task paradigm can improve motor and cognitive performance. It can be used to identify individuals' motor and cognitive abilities by combining motor and cognitive demands while performing two or more tasks simultaneously. For example, studies reported that cognitive and motor dual-task training could improve the single and dual-task walking performance in the elderly (Kuo et al., 2022) and promote the dynamic balance performance of children (Hoshyari et al., 2022).

Criteria such as appropriateness of tasks to age and clinical condition, tasks similar to daily life situations, calculation of dual-task cost, assessing single-task performance in the baseline, randomization of the task order, giving clear instructions, use of homogeneous samples, the same data collection methods and the same study variables of gait and static postural control, are suggested to be included future studies. In addition, we suggest more studies to analyze the effect of a secondary motor task with different difficulty levels on static and dynamic postural control tasks because most studies focus on the cognitive task. Besides, more challenging tasks can help detect early signs of decline in postural control (Laessoe et al., 2008).

Conclusions

According to the results of the present review, the association of secondary motor tasks with other motor activities, such as static or dynamic postural control tasks while performing other motor tasks, negatively affects the postural control performance during motor dual-tasks, regardless of the age group or the clinical condition.

The motor tasks were classified according to the complexity and novelty of the tasks, based on the tasks found in studies included in this review, and on the existing taxonomy model for classifying tasks. However, we conclude that the classification of task's difficulty or complexity depends on the author's interpretation and performer characteristics, making it challenging to build a standard classification of tasks.

We suggest more studies with motor tasks and different difficulty levels because the effects of motor tasks on gait and static postural control are scarce and use various methodologies. Therefore, further studies are necessary to analyze the effect of a secondary motor task on gait and postural control tasks.

Declaration of interest

No conflicts of interest to declare.

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