Measuring the cost of cognitive-motor dual tasking during walking in multiple sclerosis

Carmela Leone, Francesco Patti and Peter Feys

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Topical Review

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Abstract: Purposeful, safe locomotion requires higher-level cortical processes, to meet the real-life demands of walking while performing concurrent cognitive tasks (e.g. recalling a shopping list or attending to a conversation). The assessment of walking and a secondary cognitive task under these 'dual tasking' conditions may represent a more valid outcome measure in multiple sclerosis (MS), by examining the occurrence and magnitude of the cognitive-motor interference of walking. This topical review provides a state-of-the-art overview of research into dual-tasking during walking in persons with MS, based on 14 recent papers. Studies consistently demonstrate a slowing of ambulation under dual tasking, regardless of the cognitive task demand, the stage of the disease and the disability level. The reciprocal effect of walking on the cognitive tasks was rarely assessed. We present our main findings, highlight the different factors contributing to dual-task deficits, identify methodological shortcomings and offer recommendations for constructing dual-tasking paradigms useful in clinical practice and research.

Keywords: multiple sclerosis, gait, cognition, attention, dual-tasking, cognitive-motor interference.

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Introduction

Evidence in humans supports that safe and functional goal-oriented locomotion is not a merely automatic process, but requires higher-level cognitive input, highlighting the strong relationship existing between cognitive function and walking.[1,2] Deficits in attention and executive function are independently associated with the risk of postural instability, impairment in activities of daily living, and future falls.[1] Deficits in walking and in cognitive function are two well-recognized features of multiple sclerosis (MS), with up to 85% of persons with MS complaining of impaired ambulation[3] and up to 65% of persons with MS having demonstrable cognitive impairment.[4]

In MS, there is a need for more meaningful outcome measures enabling clinicians and researchers to better address real-life performance. Assessing walking and cognitive abilities separately may not truly reflect everyday activity, where people are often required to do a motor task and perform a cognitive task at once, the so-called 'dual tasking' (DT). Assessment of walking combined with a cognitive task (DT during walking) may have face validity for measuring real-life impairment in persons with MS, perhaps superior to the current measures of gait speed and balance (i.e. Timed 25 Walk test, 10 Meter Walk test and Timed Up and Go test).

Whenever one or both tasks shows a decrement during DT performance, compared with individual testing (walking or cognitive tasks alone), this is likely to indicate the occurrence of cognitive-motor interference (CMI).[1] The CMI can be expressed in terms of 'dual-task cost' (DTC), calculated as the relative ratio of single task to DT, controlling for single-task performance, as per equation (1) obtained from Baddeley et al.[5]:

$$\text{DTC} = (\text{single-task} - \text{dual-task})/\text{single-task} \times 100 \quad (1)$$

Although the precise mechanisms underlying CMI are not fully understood, two main theories have been suggested: the capacity-sharing and bottleneck models.[6,7] The former theory maintains that each kind of task draws from limited attention resources; hence, if the resources required by two or more tasks exceeds the limited brain capacity, a CMI will arise.[6] This theory also assumes that it is possible to voluntarily allocate capacity to a specific task, even when both

Correspondence to:
Carmela Leone
REVAL Rehabilitation Research Center, BIOMED Biomedical Research Institute, Universiteit Hasselt, Martelarenlaan 42, BE 3500 Hasselt, Belgium.
carmela.leone@uhasselt.be

Carmela Leone
Peter Feys
REVAL Rehabilitation Research Center, BIOMED Biomedical Research Institute, Hasselt University, Hasselt, Belgium

Francesco Patti
Section of Neurosciences University of Catania, Catania, Italy

tasks are over-learned and largely automatic. Differences in DT performance can result from individual variations in overall capacity and intra-individual variability (i.e. arousals, motivation, energy or fatigue).[8] The bottleneck theory proposes that if two tasks are processed by neural pathways involving shared networks, a bottleneck is created in the information processing, resulting in either slowed gait or delayed performance of the second task.[7] Neuroimaging investigations during dual tasking show the activation of specific brain areas, such as the anterior cingulate cortex and prefrontal cortex, including the inferior frontal gyrus.[9,10]

A number of studies conducted in young and older people, as well as in other neurological diseases (dementia and Parkinson's disease) have used DT paradigms during walking to gauge the interactions between cognition, gait and the risk of falls.[11–13] The seminal 'stops walking while talking' study in older people living in a nursing home shows that the inability to maintain a conversation while walking, suggesting DT interference, is a marker of future falls.[11] DT deficits are shown in people with cognitive impairment, increasing with the complexity of the DT and the severity of the cognitive dysfunction.[13] Patients with Parkinson's disease display, during DT conditions, greater gait asymmetry, reduced bilateral coordination and increased gait variability.[13] The latter two variables, together with reduced velocity, are associated with an increased risk for falling in this population.[13] A recent meta-analysis on CMI while walking concludes that gait speed under DT conditions is able to differentiate healthy participants from those with neurological deficits.[14] This evidence from outside the field of MS supports the clinical utility of DT paradigms for detecting gait impairment and predicting falls.[15]

Recently, research in MS has shown an increasing interest on DT methodology as a way of investigating motor and cognitive interference and measuring gait deficits.[16–29] The aim of this topical review is to provide a comprehensive state-of-the-art overview of DT during walking in persons with MS, by discussing the reported effects on walking and cognitive tasks, analyzing the main contributing factors to DT deficits and addressing current gaps in the literature. Several methodological considerations useful for future research in constructing DT outcome measures are offered.

Review of dual tasking effects during walking in persons with MS

We identified 14 recent studies investigating the effects of DT during walking in persons with MS, by searching the electronic databases *Pubmed* and *Web of Knowledge*. Our search strategy included the following Medical Subject Heading (MeSH) terms and keywords: 'multiple sclerosis', 'gait', 'walking', 'fall', 'falling', 'dual task' and 'dual tasking'. Our study characteristics and main findings are summarized in Table 1. Some studies[17–19, 22-23, 28] clearly reported the effects of DT on the single task performances by using the DTC formula of Baddeley et al.[5] (equation (1) within this review), two studies reported a percentage change between the single- and dual-task condition[24–25], while we had to calculate the DTC for the other papers (Table 1).

Effects of DT on walking

The principal detrimental effect of DT performance on walking was a reduction of gait velocity timed over a short walking distance[16–29]; and in some studies, it was also measured by spatio-temporal gait analysis.[17–23, 25,26, 28,29] Other effects of DT performance were reported on step length,[19–23, 28] double support time as percentage of gait cycle[16, 23,27,28] and cadence.[19, 22, 26, 28]

Whilst step length changes may be related to gait speed reduction, the less frequent impairment of cadence may be explained by the hypothesis that it is controlled by different mechanisms involving the brainstem and spinal cord.[30] The increase in double support duration is suggested to be a compensatory strategy to maintain walking stability, during a challenging DT condition.[27]

The consistent slowing down of walking, during dual- compared to single-tasking conditions, supports the notion that gait speed-control areas may be interlinked with the networks of executive functions (i.e. prefrontal and cingulate cortex), which have been related to DT performance.[1] Imaging studies show that gait speed is dependent on prefrontal cortex activation[31,32]; therefore, CMI while walking may occur when the concurrent tasks compete for these shared neural networks.[33]

As seen in Table 1, many different secondary cognitive tasks were applied in the various studies. An important finding is that the effects of DT on walking have been found, regardless of the nature of the added cognitive task. Although different cognitive tasks were added across studies, hampering direct comparisons of study results, this finding should support the capacity-sharing model. According to this model, performance of two attention-demanding tasks reduces the functioning of one or both tasks, if capacity limits are exceeded, regardless of the specific nature of the tasks.[6]

It could be argued that, given their frequent motor and cognitive deficits, persons with MS may have a

Table 1. Overview of experimental methods and results of studies investigating the effects of dual tasking in persons with MS.

Study sample	Sex (F/M)	Age (yrs)[a]	EDSS	Cognitive assessment	PRO	Motor task (walking at self-selected speed)	Cognitive task	Instructions	Velocity of single task	DTC Velocity	DTC Cognitive task
Allali et al., 2014; *n* PwMS = 9	5/4	38.1 ± 9.5	2.9 ± 1.1[a]	SRT, SWCT, TMT A and B, TAP, WLG, DS, SDMT	16-items FES-I, HADS	Opto-electronic system	(1) FC; (2) BC; (3) WLG sem; (4) WLG ph	"walk and perform the cognitive task at the best of their capacity; no task prioritization"	PwMS: 1.1 ± 0.1 m/s	−9.6%[d](1); −9.6%[d](2) −16.6%[d](3); −20.2%[d](4) (3) and (4) significantly improved	–
Allali et al., 2014 PwMS = 25 ; HC = 25	16/9 18/7	39.5 ± 8.3 35.7 ± 8.7	1.9 ± 1.0[a]	SRT, SWCT, TMT A and B, TAP, DS, SDMT	–	Opto-electronic system	(1) FC; (2) BC; (3) WLG sem; (4) WLG ph	"to combine both tasks at their best capacity, without task prioritization"	PwMS: 1.2 ± 0.1 m/s HC: 1.4 ± 0.1 m/s	PwMS:[e] −5.6%[d](1); −8.1%[d](2) −17.7%[d](3); −23.4%[d](4) HC:[e] −2.9%[d](1); −10.9%[d](2) −15.3%[d](3); −21.2%[d](4)	PwMS:[e] −24.6%[d](1); −13.2%[d](2) +9.9%[d](3);+3.2%[d](4) HC:[e] −33.4%[d](1);16.3%[d](2) +2.2%[d](3); – 8.1%[d](4)
Gunn et al., 2013 PwMS = 148	114/34	57 ± 10	Range 3.5 – 6.5	SDMT	–	10-meter WT	Serial– 7 subtraction	Not specified	Not provided	PwMS Non-fallers: −26.7% PwMS Fallers: −34.4%	–
Hamilton et al., 2009 PwMS = 18 HC = 18	16/2 12/6	39.2 ± 8.1 39.2 ± 11.4	2.7 ± 1.6[a] (0 – 5.5)	ACE-R	HADS, MFIS, CFQ	4.6 m GAITRite walkway (in a 18-m -long circuit)	(1) Titrated DS; (2) Fixed DS	Not specified	PwMS: 1.1 ± 0.2 m/s HC: 1.4 ± 0.9 m/s	PwMS: − 8.6% (1); –10.7% (2) HC: – 1.6% (1); –2.1% (2)	PwMS: -14.4% (1); –17% (2) HC: -2.8% (1); +1.6% (2)
Kalron et al., 2010 PwMS = 52 HC = 28	36/16 20/8	35.2 ± 1.3 32.8 ± 1.2	1.7[a]± 0.2[c] (0-5)	–	–	4.6 m GAITRite walkway	Mod. WLG	"perform the mod. WLG test while walking on the GAITRite"	PwMS. 1.2 ± 0.3 m/s HC: 1.3 ± 0.2 m/s	PwMS: −7.4%[d] HC: − 1%[d]	–
Kramer et al., 2014 PwMS = 70	44/17	47 ± 9	3 ± 1	–	–	10-m Optogait corridor	Questions (i.e. "How many surfaces does a cube have?")	Not specified	PwMS: 1.2 ± 0.2 m/s	PwMS: −12.9%[d,f]	–
Learmonth et al, 2014 PwMS = 61	46/15	50.8 ± 9.3	4 ± 2.7[b]	–	–	4.6 m GAITRite walkway	Alternate letters of alphabet	"concentrate on reciting alternate letters rather than on walking"	PwMS: 102.7 ± 28.6 m/s	PwMS: − 15%	–
Motl et al., 2013 PwMS = 82	63/19	49.4 ± 9.1	3.5 ± 3.0[b] self-reported	SDMT	HADS, FSS	4.6 m GAITRite walkway	Mod. WLG	Not specified	PwMS: 1 ± 0.3 m/s	PwMS: −13.5%	–
Nogueira et al., 2013 PwMS = 12 HC = 12	9/3 9/3	30.6 ± 5.0; 33.2 ± 7.3	Range 0 –1.5	–	–	10m-TWT along a 14-m walkway	Serial − 3 subtraction	"to perform the 10m-TWT while executing an arithmetic task"	PwMS 1.3 ± 0.2 m/s HC 1.2 ± 0.1 m/s	PwMS: −6.3%[d,g] HC: −2.5%[d,g]	–
Nogueira et al., 2013 PwMS = 120	90/30	38.1 ± 12.3	2.7 ± 2.0[a]	–	MFIS	10-m TWT along a 14-m walkway	Serial– 3 subtraction	"to perform 10-m TWT while executing an arithmetic task."	PwMS at lower speed: 1.4 ± 0.1 m/s PwMS at normal speed: 0.9 ± 0.3 m/s	PwMS at lower speed: − 9.3% PwMS at normal speed: −15.7%	–

(Continued)

Table 1. (Continued)

Study sample	Sex (F/M)	Age (yrs)[a]	EDSS	Cognitive assessment	PRO	Motor task (walking at self-selected speed)	Cognitive task	Instructions	Velocity of single task	DTC Velocity	DTC Cognitive task
Sosnoff et al., 2011 PwMS = 77	61/16	Mi: 43.3 ± 10.7 Mo: 53.3 ± 8.5 Se: 58 ± 8.2	Mi: 2.5 ± 0.7[b] Mo: 4.5 ± 0.5[b] Se: 6.0 ± 0.2[b]	–	–	26-ft over a GAITRite walkway	Mod. WLG	"list as many fruits, vegetables and words beginning with letter D as possible and walk on the mat"	PwMS: Mi 1.3 ± 0.2 m/s Mo 1.1 ± 0.2 m/s Se 0.8 ± 0.2 m/s	PwMS: Mi = −7.2% Mo = −13.4% Se = − 13.6%	–
Sosnoff et al., 2013 PwMS = 96	–	52.7 ± 11.2	4.5 ± 3.0[b] (2.0–6.5)	SDMT	–	26-ft over a GAITRite walkway	Mod. WLG	"begin uttering words as soon as they initiated their walking"	Not provided	PwMS: −12.5% (range 14.1%–42.4%)	–
Wajda et al., 2013 PwMS = 33	28/5	60 ± 6.1	6 ± 2.0[b] (0 –6) self-reported	–	–	5 meters GAITRite walkway	Mod. WLG	"to utter as many words as possible with the letter D, and as many fruits and vegetables"	PwMS 0.8 ±0.3 m/s	PwMS: −11.9%	–
Wajda et al., 2013 PwMS = 10 HC = 10	9/1 5/5	54.3 ± 11.0 34.4 ± 8.9	Range 2.5 – 4.0	–	–	Forward and backward 10-m including an 8-m GAITRite walkway	Mod. WLG	"list as many fruits and vegetables in (1) and states in the US as possible in (2)"	PwMS: 1.1 ± 0.4 m/s HC: 1.4 ± 0.2 m/s	PwMS: −13.9%[d] HC: − 3.7%[d]	Single task data not provided Data during DT: PwMS: 1 ± 0.3 word/s HC:1.5 ± 0.3 word/s

[a]Mean ± SD
[b]Median ± IQR
[c]SE
[d]DTC calculated according to Baddeley's formula
[e]No significant differences between groups
[f]Mean value of 3-groups
[g]No significant difference, compared with the single-task condition
ACE-R: Addenbrooke's Cognitive Examination Revised; BC: backwards-counting; CFQ: cognitive failure questionnaire; DTC: dual task cost; DS: digit span; EDSS: Expanded Disability Status Scale; F: female; FC: forward-counting; FES-I: Falls Efficacy Scale – International; FSS: Fatigue Severity Scale; HADS: Hospital Anxiety Depression Scale; HC: healthy controls; IQR: inter-quartile range; M: male; MFIS: Modified Fatigue Impact Scale; Mi: mild; Mo: moderate; Mod.WLG: modified word list generation; MS: multiple sclerosis; Ph: phonemic; PROs: patient reported outcomes; PwMS: persons with MS; SD: standard deviation; SDMT: Symbol Digit Modality Test; SE: severe; Sem: semantic; SRT: selective reminding test; SWCT: Stroop word color test; TAP: Test of Attentional Performance; TMT: Trial Making Test; 10m-TWT: 10-meter Timed Walk Test; yrs: years; WLG: Word List Generation

more limited central capacity or, in other words, they would be more easily overloaded under DT conditions. The same theory also proposes that as attention is split, dividing attention, performance of the two attention-demanding tasks may be altered, even if capacity is not yet exceeded. According to the bottleneck theory,[7] the various cognitive tasks performed in the different studies might have created structural interference at a simple motor level with walking, as all the cognitive tasks used do have a motor component requiring speech. Nonetheless, one can argue that cognitive tasks such as counting, the alternate-letter alphabet and serial subtracting, which are called mental-tracking tasks because they require holding information in the mind while performing a mental process (as well as verbal fluency tasks) share more complex neural networks connecting different brain regions, which are interlinked with those of gait control; thus, suggesting a higher-level bottleneck.[34]

Effects of DT on cognitive tasks

In contrast to the systematic reporting of the detrimental effect of DT on walking velocity, only two studies reported the performance (and changes compared to single performance) of a cognitive task under DT conditions,[17, 21] with contradictory results. A study by Hamilton et al.[17] found a detrimental effect of DT on cognitive performance, but it was only significant during the more difficult cognitive tasks (fixed digit span). The authors hypothesized that this could be related to: a reduction in working memory capacity, task demand, use of different strategies, confounding factors or divided attention deficits; however, the concurrent reduction of both tasks (walking and digit span) in this study might exclude a task prioritization concern.

Conversely, Allali et al.[21] did not find significant difference in cognitive performance between single and DT conditions, suggesting a 'wrong' prioritization strategy of the cognitive task over walking.[35] It is possible that this pattern of gait slowing while the secondary cognitive task remains stable may be specific to the patient groups included in the study. A low physical disability in the trial cohort might allow people to allocate attention to the cognitive tasks and win preference to maintaining walking speed. We do not have comparable data under DT in persons with MS with a higher disability level, therefore it is unclear what kind of DT behavior would be adopted by people with greater physical impairment.

Contributing factors on DT effects during walking

When assessing DT changes, it is important to consider individual characteristics such as: physical and cognitive impairments, age, concomitant medication and other symptoms, as well as the complexity of both walking and the concurrent cognitive tasks.[1] Table 1 summarizes some of the factors which may influence DT performance.

The role of physical disability level is not clearly established, since DTC were found irrespective of the disability level; however, one study reports a greater DTC in the more disabled persons with MS, which may hypothetically be related to a higher prevalence of cognitive dysfunction with disease progression[36] or to the subjects' increased walking impairment, requiring greater cognitive resources. Both hypotheses are based on increased overloading of the working memory system; however, the presence of DTC in persons with MS without disability suggests that physical status cannot entirely explain the CMI.

It is surprising that the cognitive contribution on DT deficits was poorly investigated in these studies focusing on CMI in persons with MS. In fact, only two studies performed a comprehensive neuropsychological assessment,[21,22] while the others only measured one single cognitive domain, without investigating executive functions and divided attention,[18,19] or used a generic cognitive assessment that was not specific for MS-related cognitive impairment.[17] Indeed, it has been well-recognized that specific cognitive functions, such as divided or alternating attention, response inhibition, set shifting and working memory may be particularly relevant to DT during walking.[1] Findings from the study of the Parkinson's disease population suggest the magnitude of the DT impact on gait is directly related to the underlying cognitive dysfunction.[35] Indeed, only patients with executive dysfunction are shown to have a greater DTC associated with an increased falls risk.[35]

The domain and difficulty level of the cognitive tasks may have an important impact on DT effects during walking.[1] A recent meta-analysis, which analyzed the CMI during walking in healthy subjects and in people with neurological diseases supports their role, concluding that cognitive tasks involving internal interfering factors (i.e. mental tracking and verbal fluency tasks) seem to disturb gait performance more than those involving external interfering factors (i.e. reaction time tasks).[14] Moreover, cognitive tasks involving verbal spoken performance may create a 'triple-task' in which the cognitive task complexity interacts with both the articulatory demands of the response modality, and the motor demands of gait.[37] Table 1 reports all the cognitive tasks used in MS and illustrates that most studies have only allowed one secondary cognitive task, so that it still remains unknown which task (type and difficulty) has most detrimental impact on DT performance.

Another notable observation, also illustrated in Table 1, is that the walking tasks were mostly assessed at a self-selected speed, whereas their fastest walking speed may be more relevant in daily life and may require more cognitive and motor resources. Most studies measured forward walking only. Only one study evaluated the effect of motor task demand on DT changes, using walking forward and backward, under single and DT conditions. Backward walking with a simultaneous cognitive task was related with greater DTC of walking in persons with MS, as compared to healthy subjects and compared to forward walking.[26] This finding may be explained by the inability to use compensatory strategies, such as vision, to execute the motor task.

Another important contributing factor to DT changes is task prioritization instructions. It has been suggested that the DTC of walking, and related increased fall risk, may be due to an inappropriate prioritization strategy. Young healthy subjects, and to a certain degree, older healthy subjects are likely to prioritize gait over the cognitive task.[35] The lack of prioritization instructions in MS studies may be a relevant concern of DT methodology; however, this lack of instructions might also allow people to decide unconsciously which task to prioritize, as would actually occur in everyday life, albeit for scientific purposes, to assess the same DT paradigm performed according to different task priority/ies would allow the determination of which behavior most closely resembles the spontaneous, self-selected strategy.

It is well-established that the DTC of walking increases with age among healthy adults,[14,38,39] but only one study reports a significant correlation between age and DTC in persons with MS.[18] Some symptomatic drugs may interfere with attention capacity, yet medication-related factors have never been reported in MS studies on DT. Finally, the contribution in the DTC of walking of several 'invisible symptoms', which are also common in persons with MS, such as fatigue, depression, pain or anxiety, has been poorly investigated; as only one study reports that there is a significant association of DTC with symptomatic fatigue, as measured by the Modified Fatigue Impact Scale.[17]

Dual tasking assessment as an outcome measure

The overall findings from studies conducted in MS, as in other neurological diseases, suggest that DT may be a holistic method suitable for detecting and measuring disability, disease progression and intervention effectiveness. DT assessment, by unmasking subtle gait deficits, may be an early marker of impairment in real-life walking performance, even in people with no or very low disability. DTC is found to be greater in people with higher disability, whom are known to use more effort for walking in community settings. In these patients, DT may be more suitable to evaluate disease progression. DTC, as a measure of gait or cognitive deficits, seems to have face validity for assessing everyday life mobility including falls, walking and cognitive abilities. These features may make DTC superior to the current measures of just walking speed or balance. The DTC may also serve as a trial outcome measure, reflecting more accurately disease severity, as it encompasses both motor and cognitive abilities, in contrast to the Expanded Disability Status Scale (EDSS), which is heavily based upon walking distance. So far, only one recent study uses walking and balance-based DT performances to assess the effect of a 3-week balance training program in persons with MS.[29] Although DT gait changes have been low-to-moderately correlated with the risk of falling in MS,[22] the role of DT as a predictor of falls has yet to be investigated by means of longitudinal studies. One could also advocate the superiority of DT assessment to the single cognitive tests that are commonly performed in the sitting position, and of which the relation with real-world behavior is not completely understood; however, no longitudinal studies on disease progression have been conducted yet, except for one interventional study, which shows a significant decrease of DTC after 1 year of specific MS treatment.[20]

Studies investigating the psychometric properties of DT paradigms in MS are now warranted. We recommend firstly, to find the most appropriate interfering DT paradigm, by addressing the shortcomings in current literature, and then assessing its test-retest reliability (practice/fatigue effects), concurrent validity (i.e. falls), measurement error and the quantification of clinically meaningful changes. DT paradigms could also be embedded in rehabilitation strategies for MS.[29] Recent findings from interventional studies carried out in other neurological diseases suggest the effectiveness of DT training in walking as a rehabilitation technique, enabling better results on both motor and cognitive outcome measures, compared to motor training alone.[40,41]

Methodological considerations

Multiple methodological issues have yet to be standardized. Most studies do not compare results with healthy controls and do not explicitly provide instructions about how to prioritize one task over the other. A standardized formula for measuring the DTC exists, but it is not always reported. The choice of the concurrent task varies and there is no consensus on which cognitive task optimally creates the appropriate interference. Many of the tasks used require a verbal response modality, without taking into account the potential structural interference of speech articulation on walking. Therefore, some consideration should concern the choice of the concurrent task.

The concurrent task should be difficult enough to load the attention-related system, but not to provoke stress or anxiety. The difficulty of the task depends on an individual's ability. Tasks requiring mathematical skills (i.e. serial 7 subtractions) may create minimal loading of attention in a subject whom is highly skilled with calculations, whereas a verbal fluency task may be difficult in subjects with language difficulties. One way to control for these individual differences could be to adjust the DT difficulty, relative to the person's single-task ability (i.e. titrated digit span).

Another concern is the consistency of the attention load required during DT performance. Verbal fluency may be relatively easy initially, but become more difficult as the test progresses. On the other hand, independent of mathematical skills, the attention devoted to serial subtractions seems to be stable over time.

Conclusion

We believe that the time has come to move beyond the current habit of measuring motor and cognitive abilities separately, in persons with MS, where current evidence as a whole suggests that gait impairments appear or get worse under DT conditions. Whether the DTC is due to a specific divided attention deficit or to an overloading of resource capacity is still unclear. Nevertheless, the current findings in MS need to be considered with caution, as multiple methodological shortcomings have been identified: limited comparison with healthy subjects, rare assessment of cognitive task performance during DT and poor investigation of the impact of cognitive abilities. The relative impact of individual and task-related factors, as well as of motor and cognitive abilities, has not been properly investigated yet. A better understanding of CMI during walking is needed, before moving forward in constructing of standardized, reliable and valid DT paradigms.

Conflict of interest

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