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Original article

The patients' perspective on the perceived difficulties of dual-tasking: development and validation of the Dual-task Impact on Daily-living Activities Questionnaire (DIDA-Q)

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ABSTRACT

Background: Everyday-life activities often require performing dual tasks (DT), with consequent possible occurrence of motor-cognitive or motor-motor interference. This could reduce quality of life, in particular in people with neurological diseases. However, there is lack of validated tools to assess the patients' perspective on DT difficulties in this population. Therefore, we developed the Dual-task Impact on Daily-living Activities-Questionnaire (DIDA-Q) and tested its psychometric properties in people with multiple sclerosis (PwMS).
Methods: Items were generated based on existing scales, DT paradigms used in previous studies and the opinion of a multi-stakeholder group, including both experts and PwMS. Twenty DT constituted the preliminary version of the DIDA-Q which was administered to 230 PwMS. The psychometric properties of the scale were evaluated including internal consistency, validity and reliability.
Results: Nineteen items survived after exploratory factor analysis, showing a three-factor solution which identifies the components mostly contributing to DT perceived difficulty (i.e., balance and mobility, cognition and upper-limb ability). The DIDA-Q appropriately fits the graded response model, with first evaluations supporting internal consistency (Cronbach's alpha=0.95), validity (70% of the hypotheses for convergent and discriminant constructs confirmed) and reliability (intraclass correlation coefficients=0.95) of this tool.
Conclusion: The DIDA-Q could be used in research and clinical settings to discriminate individuals with low vs. high cognitive-motor or motor-motor interference, and to develop and evaluate the efficacy of personalized DT rehabilitative treatments in PwMS.

1. Introduction

Historically, in the field of clinical and experimental neuroscience, it has been common practice to consider motor and cognitive functions as independent domains. This approach shaped through decades of scientific production a large number of gold-standard assessment tools evaluating either motor or cognitive performance separately in different clinical conditions (Golan et al., 2019; Langdon, 2015; Opara et al., 2017). However, the multifaceted nature of the stimuli coming from the surrounding world requires responses that often imply the simultaneous performance of a motor and a cognitive task, i.e., dual tasks (DT).

Common DT involve automated or semi-automated motor actions such as walking, and additional cognitive or motor tasks, e.g., talking to a friend, remembering the shopping list in a supermarket or performing upper limb activities. During DT, one or both tasks may show a performance decrement, indicating the occurrence of cognitive-motor (CMI) or motor-motor (MMI) interference (Yogev-Seligmann et al., 2008). CMI and MMI have been found in healthy subjects (Subramaniam and Bhatt, 2017), elderly (Bohle et al., 2019; Santos et al., 2018) and people with neurological pathologies (McIsaac et al., 2018; Monticone et al., 2014), such as Parkinson's disease or multiple sclerosis (MS). A recent meta-analysis on CMI showed that walking speed changes

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due to DT can differentiate healthy participants from those with neurological deficit (Al-Yahya et al., 2011), supporting the clinical utility of DT outcomes to detect and measure disability, disease progression and intervention effectiveness. Although in its infancy with respect to other neurological conditions, DT literature in MS showed promising results, both as assessment and rehabilitative methods (Veldkamp et al., 2019; Veldkamp et al., 2019b).

MS is a chronic immune-mediated disease, involving demyelination and axonal damage within the central nervous system. Functional brain changes have been observed since the first phases of the disease (Giorgio et al., 2015; Pantano, 2002), providing people with MS (PwMS) with compensatory strategies that may help to overcome single tasks requirements (Bonzano et al., 2020, 2019, 2009; Dattola et al., 2017). In this frame, DT assessment could be a holistic method suitable to unmask subtle deficits and an early marker of impairment in real-life performance. However, there is no consensus on which tasks combination creates higher interference (Leone et al., 2015; Patel et al., 2014). The effects of DT on walking (e.g., reduction of gait velocity, increase of double support duration) (Kalron et al., 2010; Learmonth et al., 2014; Pau et al., 2018) may depend on the type of the concurrent task in MS: for example, many cognitive tasks require a verbal response modality (talking, counting), adding the potential interference of speech articulation on walking. At the same time, different walking and balance requirements under DT condition may produce specific detrimental effects on cognitive performance (Hamilton et al., 2009) or alter the attention allocated to the concomitant tasks (i.e., altered prioritization strategy) in PwMS, depending on the perceived difficulty of the tasks (Allali et al., 2014).

The individual perspective of the DT that might mostly interfere with daily-living activities could be useful to integrate the functional assessment of PwMS. Indeed, patient-reported outcomes (PROs) have recently received great attention from the scientific community (Multiple Sclerosis International Federation, 2019) for their potential role in the identification of information useful to predict the disease progression (Brichetto et al., 2020), supporting the clinicians in healthcare decision-making. However, there is still lack of validated PROs on DT. The only validated scale investigating the perceived difficulty during two simultaneous tasks, namely the Divided Attention Questionnaire – DAQ, is a list of 15 questions including different activities of daily living (ADL) (Salthouse and Siedlecki, 2005; Tun and Wingfield, 1995). Given the main purpose of the questionnaire (i.e., assessing divided attention), this tool presents some limitations when adapted to evaluate DT ability. First, most of the questions involve the combinations of two tasks requiring high levels of attention (e.g., driving and reading signs, reading and watching TV); thus common DT including automated or semi-automated motor tasks such as standing or walking are underrepresented. Moreover, the DAQ provides a single score, neglecting possible differences in the perceived difficulties experienced during motor-cognitive or motor-motor tasks. Finally, some items describe generic situations (e.g., “having a conversation”, “doing chores”); this may be sufficient to evoke the need of high levels of attention, but does not allow the identification of the specific demand generating DT interference (in the previous examples: “talking” or “listening”; “concentrating” or “manipulating objects”, respectively). Few other studies reported the use of questionnaires on DT (Evans et al., 2009; Strouwen et al., 2014), but they have been used as screening checklists and their psychometric properties have not been assessed through rigorous validation methodology.

Therefore, the aims of the present study were (i) to develop a new PRO investigating the patients’ perspective on DT impact on ADL and (ii) to preliminarily test the psychometric properties of the new questionnaire in PwMS.

2. Materials and Methods

2.1. Study design

The present work is part of a project supported by the Italian MS Foundation (FISM 2016/B/4) on the study of behavioural and neural correlates of DT negotiation in MS, aiming at investigating the processes of CMI in real-world contexts. As first step, we developed a new PRO on DT, the Dual-Task Impact on Daily-living Activities Questionnaire

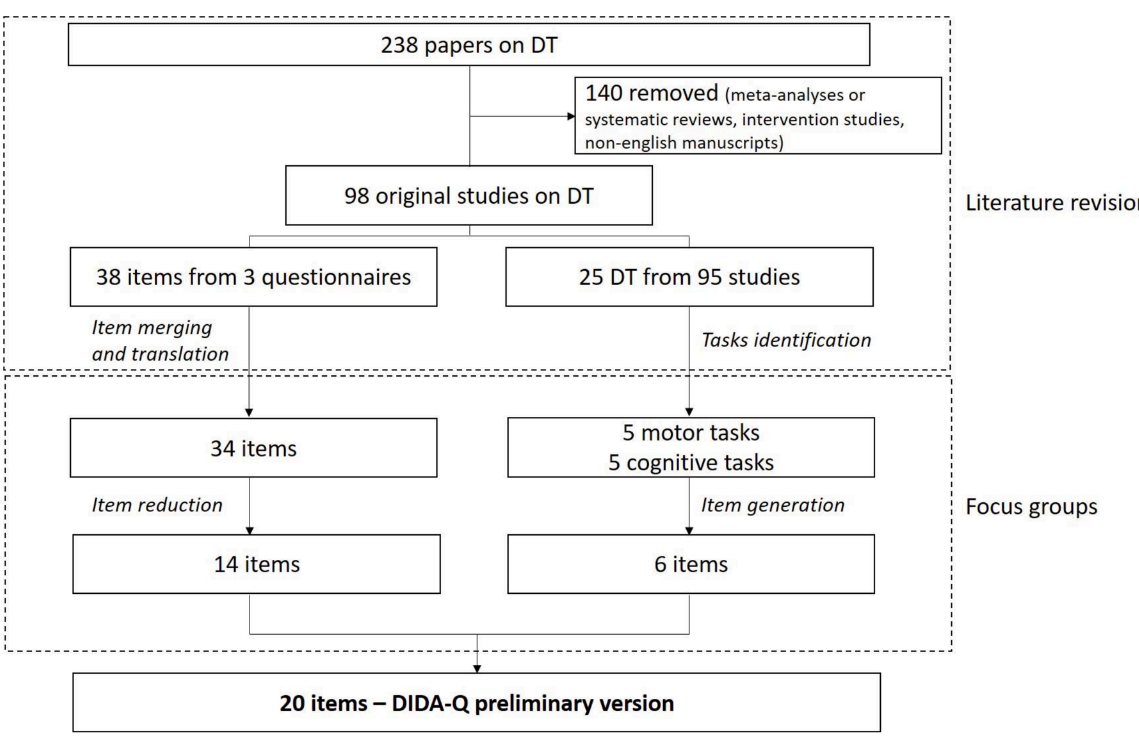

Figure 1. Flow chart of item selection, revision and generation of DIDA-Q from the literature revision process and the focus group sessions involving a multi-stakeholder team.

(DIDA-Q), and validated its psychometric properties on a large sample of PwMS.

2.2. Instrument development and item generation

The DIDA-Q development process was based on a literature revision performed by an expert committee (i.e. two rehabilitation physicians and two physical therapists), followed by focus groups with different MS stakeholders, namely the expert committee, two psychologists, two caregivers and two PwMS (Figure 1).

The literature search returned 238 works on DT assessment in healthy subjects and/or in people with neurological diseases. Only original studies written in English which did not focus on training or other intervention treatments were considered. Of the remaining 98 studies, 3 included questionnaires, surveys or checklists on DT (Evans et al., 2009; Salthouse and Siedlecki, 2005; Strouwen et al., 2014). The expert committee extracted the list of 38 items from these three existing measures and, after the merging of the items investigating the same DT, translated the remaining 34 items into Italian by using the procedure adopted in previous studies on the development and validation of new PROs (Mokkink et al., 2015). Moreover, the expert committee identified the most commonly used motor and cognitive tasks in the DT assessment with the aim to provide information for the following item generation process: 'standing', 'normal-' and 'fast-speed gait', 'walking on non-linear paths' and 'avoiding obstacles' were chosen as motor tasks; 'visuomotor reaction time', 'executive functions', 'mental tracking', 'working memory' and 'verbal fluency' were identified as cognitive tasks.

The multi-stakeholders approach (Multi-Act, 2020) of the focus groups was devoted to take into account the point of view of different MS stakeholders, with particular attention to the perspective of patients. The aim of the first focus group was to remove the items of the existing scales which were considered not suitable for DIDA-Q. Among the criteria for removal there are: association of two cognitive tasks (i.e. divided attention assessment) (e.g. "talking to someone in the midst of a crowd of people talking") (8 items); poor and generic description of the tasks (e.g., "thinking about something", "doing some activity") (7 items); involvement of different cognitive domains (e.g., "finding your way in airport or train station" which require memory, attention and orienteering) (3 items); multitasking requirement (e.g., "spilling a drink when carrying it and talking at the same time" which involve three concurrent tasks) (2 items). At the end of this process, 14 items survived. The aim of the second focus group was the generation, followed by discussion and selection, of new items describing everyday activities involving the motor and cognitive tasks previously identified from the studies in DT assessment.

The preliminary version of the DIDA-Q consists of 20 items. A consensus approach was used during the process of items selection, revision and generation, and to approve this preliminary version.

The questionnaire was implemented with a rating structure using a Likert-type scale ranging from 0 to 4 for each item (0=no difficulty; 1=slightly difficult; 2=somewhat difficult; 3=very difficult; 4=extremely difficult), with total possible scores ranging from 0 to 80; the higher the score, the greater the difficulty in performance of the DT combination.

The preliminary version of the DIDA-Q was administered to 10 PwMS to test the clarity and intelligibility of each item and to ensure the comprehensibility of the questionnaire to patients. Minor revisions were performed after the feedbacks provided, in particular concerning the example provided in the description of the task (e.g., "Walking and phoning" has been changed into "Walking and using your phone (e.g., looking for a contact, sending a text message)").

2.3. Sample and data collection

The validation study was carried out between September 2017 and February 2018 at the Italian MS Society (AISM) Rehabilitation Centre Liguria, Genoa, Italy. We enrolled PwMS aged 18–85, who voluntarily accepted to participate in the study. Since dual tasking implies the performance of an automated or semi-automated motor action (here, walking), we excluded individuals unable to walk beyond a few steps even with aid, as detected by an Expanded Disability Status Score (EDSS) ≥ 7 (Kurtzke, 1983).

The sample size was estimated based on the recommendation to enroll a number ranging from 5 to 20 respondents per item (Rattray and Jones, 2007; Tabachnick and Fidell, 2012); here, to run a solid factor analysis and considering 15% of possible incomplete information/data loss, we aimed to include 10 respondents $\times$ 20 items = 200 + 15% = 230 participants.

All participants were asked to respond to the DIDA-Q and fill in the socio-demographic data sheet including sex, age, education and occupational status. Moreover, disease duration and disability (through the EDSS) as well as other measures of DT ability (using the DAQ), upper limb function (using the ABILHAND questionnaire)(Penta et al., 1998), independence in ADL (using the Functional Independence Measure, FIM)(Keith et al., 1987), fatigue (using the Modified Fatigue Impact Scale, MFIS)(Kos et al., 2005), and cognition (using the Symbol Digit Modalities Test, SDMT)(Benedict et al., 2017) were collected. Concerning the FIM and the MFIS, both total and subscales scores (investigating independence in self-care, FIM_{self}; sphincter control, $FIM_{sphinct}$; transfers, FIM_{transf}; locomotion, FIM_{loc}; communication, FIM_{comm}; social cognition, $FIM_{soc;}$ and motor fatigue, $MFIS_{mot}$; cognitive fatigue, $MFIS_{cog}$; psychosocial fatigue, $MFIS_{psyc}$, respectively) were used for the analyses.

In addition, 20 participants completed the DIDA-Q twice, two weeks apart, to provide a measure of test–retest reliability, required to allow appropriate analyses of stability of the questionnaire. This time interval was sufficient to minimize recall bias and to ascertain that PwMS's perception on DT difficulty remained unchanged (Salthouse and Siedlecki, 2005).

The project was approved by the local Ethics Committee and all patients signed an informed consent form prior to their inclusion in the study.

2.4. Statistical analysis

Data were analyzed using the STATA Statistical Software, release 15 (StataCorp LP, College Station, TX, USA). Descriptive statistics were used to summarize the demographic data and single items. Data quality and items distribution were analyzed via missing values and score distribution. Data quality was rated as acceptable if item scores were missing in less than 10% of the patients. Exploratory factor analysis was performed for the initial assessment of DIDA-Q construct validity (Thompson, 2004). Factors were extracted by principal component factor analysis with a varimax orthogonal rotation method. Bartlett's test of Sphericity (BTS) and a Kaiser-Meyer-Olkin (KMO) test must be conducted to confirm the suitability of data. BTS with $p < 0.05$ and a KMO value of 0.60 were considered suitable when running the EFA (Cerny and Kaiser, 1977; Kaiser, 1974). The Kaiser's criterion for factors with an eigenvalue ≥ 1 was used as a criterion for component extraction. Factor loadings greater than 0.40 were considered significant. Items that loaded in a same way on more than one factor and that had loadings $<$ 0.40 were deleted; also, items with cross loading greater than 0.40 were dropped (Nunnally, 1978), as they would determine high instability and poor contribution in terms of construct to the instrument. Model fit was tested with the ratio between chi-square and degree of freedom (χ^2/d.f.) (good if ≤ 3) and the root mean square error of approximation (RMSEA) (good if ≤ 0.08) (Hu and Bentler, 1999). We reported these statistics using the Satorra-Bentler (SB) adjustment ($\chi^2/d.f._{SB}$ and $RMSEA_{SB}$) given the non-normal distribution of the scale items (Satorra and Bentler, 1994); to improve the model fit we considered the covariance of error terms.

Reliability of DIDA-Q was assessed by internal consistency and item reliability. The internal consistency was estimated by Cronbach's alpha coefficient and average inter-item correlation. The statistically acceptable Cronbach's alpha coefficient should be > 0.7 (Streiner and Norman, 2001), and average inter-item correlations should be comprised between 0.30 and 0.70 (Nunnally and Bernstein, 1994). Item reliabilities were assessed by test-retest correlations, determined by calculating intraclass correlation coefficients (ICC, 2-way analysis of variance random effect model for agreement) on subscale and total scores which are expected to remain stable. An ICC value of 0.70 was recommended as a minimum standard for reliability (de Vet et al., 2006).

Construct validity of the DIDA-Q was assessed by the degree to which the DIDA-Q scores were consistent with predefined hypotheses regarding relationships between the DIDA-Q and the other measures. We formulated different hypotheses (Table 1) as following reported: moderate correlation was expected between the DIDA-Q and DAQ, because the latter is the only validated questionnaire on DT but is mainly focused on divided attention assessment; thus, these scales measure a similar but not the same constructor (hypothesis 1). Moderate correlations were also expected between the DIDA-Q and other measures assessing domains that may either influence DT (e.g., fatigue, manual dexterity, cognitive functioning) or be affected by DT ability (e.g., independence ADL) (hypotheses 2, 4, 7, 8). Low correlation was expected between the DIDA-Q and some PROs' subscales measuring different constructs (hypotheses 9-10). Moreover, a hierarchy in strength of the linear relationship between the DIDA-Q and PROs' different subscales was expected according to the domain evaluated (hypotheses 3, 5, 6). Spearman's correlations coefficients (ρ) were used for assessing all hypothesized relations between the DIDA-Q and PROs and clinical evaluation measures. Correlation was considered as low for $\rho<0.30$; moderate for ρ: 0.30–0.59; and high for $\rho\geq0.60$ (Cohen, 1988).

Known-groups validity evaluates whether an instrument can discriminate between known groups of patients that are expected to score differently on the measure of interest. Here, it was assessed by comparing with the Mann-Whitney U test the DIDA-Q scores of participants' groups with different level of disability. The groups were defined using a cut-off value of 3.5 at the EDSS, discriminating between PwMS able (EDSS≤3.5) or unable (EDSS>3.5) to walk without aid or rest for more than 500 m. Since the DIDA-Q, as previously explained, investigates DT performance involving an automated or semi-automated motor action (i.e., walking), this kind of deficit is expected to affect *per se* the DIDA-Q score.

Table 1
Specific hypotheses and correlation coefficients of the DIDA-Q with other measurement instruments

Hypothesis	Confirmed yes/no	Result (ρ)
1 Moderate correlation between the DIDA-Q and DAQ, because they measure a similar but not the same construct (i.e., DT vs. divided attention)	Yes	0.54
2 Moderate correlation between the DIDA-Q and $MFIS_{tot}$, because they measure non-similar constructs but fatigue may influence DT	No	0.67
3 Higher correlation between DIDA-Q and $MFIS_{cogn}$ and between DIDA-Q and $MFIS_{phys}$ as compared with correlation between the DIDA-Q and $MFIS_{psych}$ because cognitive and motor fatigue may influence DT more than psychosocial fatigue	Yes	0.54 vs 0.52 0.67 vs 0.52
4 Moderate correlation between the DIDA-Q and FIM_{tot} because they measure non-similar construct but daily-living activities may imply DT ability	Yes	-0.55
5 Higher correlation between DIDA-Q and FIM_{self} as compared with correlation between the DIDA-Q and $FIM_{sphinct}$ because daily-living activities such eating, bathing and dressing imply DT abilities more than the sphincter control	Yes	-0.53 vs -0.33
6 Higher correlation between DIDA-Q and FIM_{transf} as compared with correlation between the DIDA-Q and FIM_{loc} because in-home transfers including to the toilet and in the shower imply DT abilities more than walking	Yes	-0.46 vs -0.45
7 Moderate correlation between the DIDA-Q and AbilHand because they measure non-similar construct but manual dexterity may influence motor-motor DT	No	-0.61
8 Moderate correlation between the DIDA-Q and SDMT because they measure non-similar construct but cognitive function may influence motor-cognitive DT	Yes	-0.36
9 Low correlation between the DIDA-Q and FIM_{soc} because they measure non-similar construct	No	-0.35
Low correlation between the DIDA-Q and FIM_{comm} because they measure non-similar construct	Yes	-0.22

3. Results

3.1. Participant characteristics

All 230 participants (166 females, mean age=52.8±11.7 years, range 19-82 years) were analyzed given the low level of missing data (≤3%). Table 2 presents the characteristics of participants.

3.2. DIDA-Q data quality and distribution

None of the items of the DIDA-Q had missing values, indicating good acceptability. Patients used the full range in each item. Individual item mean scores ranged from 0.60 to 1.88 (Table 3). Figure 2 shows the percentages of the answers provided by the participants in each item.

3.3. Exploratory factor analysis and internal consistency

BTS was significant ($p<0.001$) and the KMO measure of sampling adequacy was 0.928, supporting the use of principal component factor analysis. Exploratory factor analysis was carried out on 20 items. One ("Walking and using an aid such as a cane or a crutch") was deleted as it had loadings < 0.40. Further analysis showed that the 19 items in the instrument yielded a three-factor solution, which cumulatively accounted for 68.9% of the total variance. The three factors identified the components mostly contributing to the DT difficulty: balance and mobility (DIDA-Q_{mob}: six items), cognition (DIDA-Q_{cog}: eight items) and upper-limb abilities (DIDA-Q_{upp}: five items). Table 3 shows the results of the principal component factor analysis after Varimax rotation. Each factor had a Cronbach's alpha value greater than 0.70. The model fit indices used in this study showed an acceptable fit for a three-dimensional scale: $\chi^2/d.f._{SB}=2.3$ and $RMSEA_{SB}=0.074$.

The final version of the new questionnaire, composed of 19 items, was thus defined, covering a range of aspects related to DT involving

Table 2
Sample's sociodemographic and clinical characteristics (n=230)

Gender, n (%)	Male Female	64 (27.8%) 166 (72.2%)
Age (yrs), mean (SD) **Range** (1.7% missing data)		52.8 (11.7) 19-82
Education, n (%) (2.6% missing data)	Primary school	60 (26.8%)
	High school	124 (55.3%)
	University degree	40 (17.9%)
Disability level, n (%) (1.7% missing data)	Low disability, EDSS score ≤3.5	46 (20.4%)
	High disability, EDSS score > 3.5	180 (79.6)
Duration of illness (yrs), mean (SD) **Range** (3.0% missing data)		18.4 (10.8) 1-48

Table 3
Factor loading

Descriptive			Rotated component matrix		
DIDA-Q Items	Mean (SD)	Inter-item correlation	Factor 1 Balance and mobility	Factor 2 Cognition	Factor 3 Upper-limb abilities
Item 12	1.14 (1.26)	0.485	0.853		
Item 10	1.88 (1.38)	0.482	0.835		
Item 7	1.57 (1.27)	0.477	0.806		
Item 9	1.09 (1.20)	0.485	0.804		
Item 11	1.77 (1.29)	0.479	0.752		
Item 19	0.60 (0.81)	0.492		0.794	
Item 4	0.71 (0.89)	0.489		0.776	
Item 5	1.15 (1.19)	0.482		0.712	
Item 13	0.81 (1.04)	0.485		0.694	
Item 18	0.96 (0.96)	0.483		0.627	
Item 3	1.46 (1.21)	0.495		0.600	
Item 8	0.87 (1.07)	0.490		0.572	
Item 15	1.55 (1.14)	0.490		0.562	
Item 6	1.46 (1.33)	0.491			0.813
Item 1	1.65 (1.32)	0.486			0.785
Item 2	1.45 (1.33)	0.491			0.783
Item 14	1.13 (1.16)	0.484			0.768
Item 17	1.63 (1.20)	0.482			0.607
Item 16	1.40 (1.31)	0.490			0.601

CMI and MMI. Total score ranged from 0 to 76; the higher the score, the greater the difficulty in DT performance.

3.4. Reliability

Internal consistency of the overall scale and identified factors was generally high. The Cronbach's alpha for all the 19 items was 0.95, and those for the three subscales were 0.93 (DIDA-Q_{mob}), 0.90 (DIDA-Q_{cog}) and 0.90 (DIDA-Q_{upp}). Similarly, the average inter-item correlation was comprised between 0.48 and 0.50. These values are in line with published satisfactory thresholds for scale reliability.

Test-retest reliability, as measured with ICC, was 0.95 for DIDA-Q total score; 0.89 for balance and mobility, 0.76 for cognition and 0.81 for upper-limb abilities subscales, showing good temporal stability. All coefficients were over the expected thresholds of 0.70, showing good test-retest reliability.

3.5. Construct validity

Table 4 presents the concurrent and discriminant validity results as indicated by the correlation coefficients between the DIDA-Q sum and subscales scores and the values of other measures. In summary, 7 out of the 10 predicted hypotheses were confirmed (see also Table 1). The DIDA-Q showed, as expected, a moderate positive correlation with the DAQ. The DIDA-Q_{cog} score showed the highest correlation with the DAQ (ρ=0.87), whilst the DIDA-Q_{mob} score the lowest (ρ=0.54). Among the hypotheses of moderate correlations, 2 out of 4 were confirmed, namely the negative correlations between the DIDA-Q and the FIM (ρ=-0.55) and between the DIDA-Q and the SDMT (ρ=-0.36). Both the MFIS and the ABILHAND showed higher correlations with the DIDA-Q than expected (ρ=0.67 and ρ=-0.61, respectively) suggesting a strong impact of fatigue and manual dexterity on DT abilities. Consistently, the MFIS subscales scores correlated with matched DIDA-Q subscales scores ($MFIS_{cog}$ and DIDA-Q_{cog}, ρ=0.59; $MFIS_{mot}$ and DIDA-Q_{mob}, ρ=0.62). Moreover, the highest correlation between the ABILHAND and the DIDA-Q was found in the DIDA-Q_{upp} subscale score (ρ=-0.66). The hypotheses of low correlation were confirmed concerning FIM_{comm} but not FIM_{soc}. In both cases, the highest (negative) correlations were found with the DIDA-Q_{cog} subscale score (ρ=-0.35 and ρ=-0.23, respectively). Furthermore, the hypothesized hierarchical order of the correlation strength between the DIDA-Q and different PROs subscales was

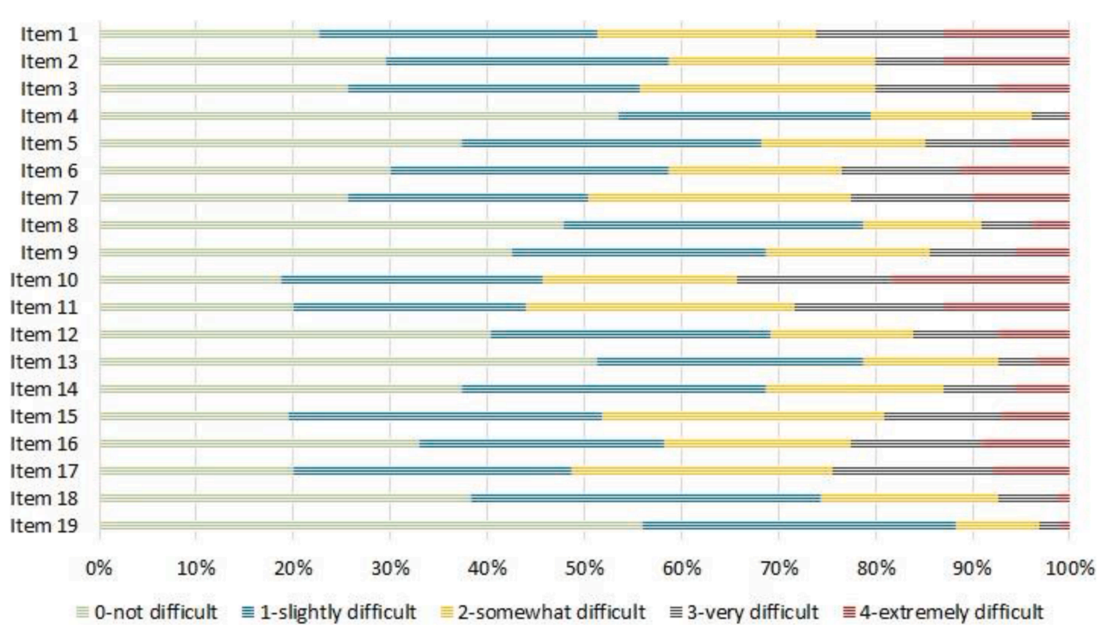

Figure 2. Distribution of participants' answers to each DIDA-Q item.

Table 4
Spearman's correlation (ρ) between DIDA-Q and PROs and clinical evaluation measures

	DIDA-Q Balance and mobility	DIDA-Q Cognition	DIDA-Q Upper-limb ability	DIDA-Q Total score
DAQ	0.544**	0.868**	0.736**	0.538**
$MFIS_{tot}$	0.564**	0.624**	0.555**	0.674**
$MFIS_{cog}$	0.390**	0.586**	0.409**	0.535**
$MFIS_{mot}$	0.623**	0.517**	0.593**	0.667**
$MFIS_{psyc}$	0.458**	0.483**	0.401**	0.520**
FIM_{tot}	-0.545**	-0.371**	-0.514**	-0.552**
FIM_{soc}	-0.296**	-0.352**	-0.284**	-0.348**
FIM_{comm}	-0.214**	-0.233**	-0.148*	-0.215*
$FIM_{sphinct}$	-0.300**	-0.233**	0.297**	-0.326**
FIM_{self}	-0.474**	-0.355**	-0.545**	-0.529**
FIM_{loc}	-0.489**	-0.237**	-0.442**	-0.446**
FIM_{transf}	-0.449**	-0.293**	-0.440**	-0.461**
Abilhand	-0.487**	-0.433**	-0.660**	-0.614**
SDMT	-0.379**	-0.306**	-0.249**	-0.356**

*p<0.05;
**p<0.001

confirmed by the results (Table 1).

3.6. Known group comparison

Known-groups validity of the instrument was shown by comparing the subscale mean scores of participants of different ranks. As expected, patients with higher EDSS reported worse scores at DIDA-Q, and the difference was significant for all three subscales (Table 5).

4. Discussion

This work presents the development and validation of the Dual-task Impact on Daily-living Activities Questionnaire (DIDA-Q), a 19-item questionnaire designed to measure the DT impact on ADL in PwMS.

The DIDA-Q was found to be multidimensional, providing both a global score on DT difficulty ranging on a 0-76 scale and three subscale scores identifying the components mostly contributing to the perceived difficulty in DT activities: balance and mobility (6 items, score range 0-24), cognition (8 items, score range 0-32) and upper-limb ability (5 items, score range 0-20).

Overall, the questionnaire properly fits the graded response model, with first evaluations supporting both validity and reliability of this tool to measure the DT impact on PwMS' daily-life activities.

The item deleted as a result of the exploratory factor analysis (EFA) (loadings < 0.40) was "Walking and using an aid such as a cane or a crutch". Although not often considered as such, the use of a mobility aid is a complex motor task that can result in an increased cognitive load (Bateni and Maki, 2005) and has been previously assessed as a DT measure (Hunter et al., 2019). However, higher levels of attention are required during the learning process of the aid correct use, whereas it might convert into an automatic task when users become more experienced. This is corroborated by the results of a recent study providing preliminary support for supraspinal sensorimotor neuroplasticity in response to rehabilitation interventions focused on task-oriented walking aid training in PwMS (Fling et al., 2019). Therefore, the answers reported by our sample in this item may differ from the others included in the DIDA-Q because PwMS consider walking with an aid closer to a single than to a dual task.

Table 5
Comparison of DIDA-Q total and subscale scores between PwMS' groups with different disability levels.

	DIDA-Q Balance and mobility	DIDA-Q Cognition	DIDA-Q Upper-limb ability	DIDA-Q Total score
EDSS≤3.5	3.8±3.5	5.5±4.9	5.1±4.0	14.4±10.2
EDSS>3.5	8.4±5.7	8.8±6.5	9.6±6.3	26.9±16.1
p value*	<0.0001	0.0006	0.0002	<0.0001

* Mann-Whitney U test

All other 19 items reached loadings cut-off values and presented in three distinct principal components after EFA. This three factor solution identifies the components which individuals may perceive as difficult if performed in DT during common every-day activities. First, *balance and mobility* may be affected in aspects such as navigating through environments, managing obstacles and modulating gait speed during a secondary simultaneous task (Bayot et al., 2018; Woollacott and Shumway-Cook, 2002). Second, *cognition* could suffer the consequences of DT in common demands, including social interaction (e.g., talking and listening to someone), safety measures (i.e., attention to the surrounding environment) and specific goals achievement (e.g., remembering things, scheduling appointments), as it was suggested that sensorimotor functions are often prioritized at the cost of cognitive performance, especially in normal and pathological aging (Li et al., 2005). Finally, *upper-limb abilities* seem to be altered by DT, even in the absence of locomotion and gait-related postural control (McIsaac and Benjapalakorn, 2015). Each factor included 5–8 items, indicating that DIDA-Q subscales are appropriate for measurement, as indicated in the literature suggesting a range of three (minimum) (Comrey and Lee, 1992) to five or more (best) (Gorsuch, 1997) variables to be included in each factor.

As previously mentioned, internal consistency both of DIDA-Q overall and subscales and of test–retest reliability were high, satisfying acceptable values of Cronbach's alpha (Streiner and Norman, 2001) and ICC coefficients (de Vet et al., 2006).

The analysis also showed satisfying results for construct validity of the DIDA-Q, as the 70% of the hypotheses were confirmed. As expected, moderate to strong positive relationships have been found between the DIDA-Q and the DAQ. Since the latter has been developed to investigate the difficulty to divide attention between two activities (basically, the assessment of a cognitive domain) (Tun and Wingfield, 1995), it is not surprising that the highest correlation was observed between DAQ and DIDA-Q_{cogn} (ρ=0.87). There is a large body of literature suggesting a role of divided attention in the control of real-world walking (Pizzamiglio et al., 2018; Wagshul et al., 2019; Yogev-Seligmann et al., 2008), in particular when associated with a demanding cognitive task as described in the DIDA-Q_{cogn} items. DAQ was also highly correlated with DIDA-Q_{upp} (ρ=0.74). This result can be explained by the high level of attention required by goal-oriented upper-limb activities. Although only a few studies explored the direct association between cognition and manual dexterity in MS producing non-univocal results (Goverover et al., 2018; Ternes et al., 2014), there is evidence that people with neurological impairment suffer from a lack of automaticity of upper-limb motor control in DT conditions (Houwink et al., 2013). This implies a higher involvement of divided attention in this population, independently from the unidimensional functioning of cognitive and motor processes (Bank et al., 2018). For similar reasons, the partial automaticity of the circuits controlling balance and locomotion (Grillner et al., 2008) can be responsible for the moderate relation between DAQ and DIDA-Q_{mob} (ρ=0.54).

Interestingly, DIDA-Q total score was moderately related to DAQ (ρ=0.54), supporting the main purpose of our work, i.e., developing and validating a new questionnaire on DT.

Among the hypotheses of moderate correlation between the DIDA-Q and other measures, those with FIM and SDMT were confirmed. FIM is a scale rating the functional status of a person based on the level of independence in a plethora of ADL, ranging from bowel and bladder control, to self-care activities, transfers and locomotion, communication and social cognition (Linacre et al., 1994). Although FIM is composed of 13 motor and 5 cognitive tasks, some dimensions assessed may require higher DT abilities than others (e.g., self-care activities such as eating, bathing and dressing imply DT abilities more than sphincter control). For this reason, a hierarchy in the correlation strength between DIDA-Q and FIM subscales has been hypothesized and confirmed by the results. SDMT is the most common test evaluating information processing, attention and concentration in MS (Benedict et al., 2017) and it is has been previously associated with DT cost in MS (Sirhan et al., 2018).

Some hypotheses were not confirmed. In particular, higher fatigue as measured with MFIS is strongly -and not moderately- related with higher DT difficulty. Although it is not the same construct as DT, it is plausible that fatigue, one of the most common and debilitating symptoms in MS (Krupp et al., 1988), affects several aspects of everyday life, including DT. This is supported by recent findings showing significant associations between DT costs and both the MFIS cognitive subscale and an electromyographic activity suggestive of muscular fatigue (Wolkorte et al., 2015). The authors discussed these results attributing high demand of both motor and cognitive resources to DT performance, corroborating our hypothesis that this ability is influenced by motor and cognitive fatigue more than by psychosocial fatigue, which is mainly associated to mood status (i.e., motivation) and participation skills (i.e., interpersonal relationships). Similarly, a negative correlation stronger than expected was found between the DIDA-Q and ABILHAND. This may be due to the types of upper-limb activities described in the DIDA-Q items, requiring fine motor control, since it was shown that the complexity of the upper-limb task influenced DT cost in both PwMS and healthy controls (Raats et al., 2019). However, it is worth noting that the strong correlation is mainly driven by the DIDA-Q_{upp} subscale.

Moreover, low negative correlations were expected between the DIDA-Q and both FIM_{soc} and FIM_{comm} subscales. Whilst the latter was confirmed, demonstrating that the underlying constructs are distinct, we found a moderate correlation between DIDA-Q and FIM_{soc}. Among the items of this subscale, there is “Problem solving”: it is reasonable that those who need higher assistance in this dimension, perceive higher levels of DT difficulty in the cognitive sub-domain (Goverover et al., 2018).

The results of t-test provide some indication on the sensitivity of DIDA-Q in capturing differences due to MS severity. Consistently with our hypothesis, patients with EDSS higher than 3.5 reported worse scores at DIDA-Q, and the differences were significant for all three subscales. The determination of EDSS 4–6 is heavily dependent on aspects of walking ability (Meyer-Moock et al., 2014), influencing the perceived difficulty of DT included in the DIDA-Q as the automatic motor component of the scale items.

In conclusion, this study shows that the DIDA-Q is a valid and reliable tool to measure DT difficulty in PwMS. Further research is recommended in order to confirm our preliminary results in a wider population, to identify cut-off values able to discriminate individuals with low vs. high cognitive-motor or motor-motor interference, and to develop and evaluate the efficacy of personalized DT rehabilitative treatments based on the score obtained at the DIDA-Q in PwMS.

CRediT authorship contribution statement

L. Pedullà: Conceptualization, Funding acquisition, Project administration, Investigation, Data curation, Validation, Writing - original draft, Visualization. **A. Tacchino:** Validation, Writing - review & editing, Visualization. **J. Podda:** Writing - review & editing, Visualization. **M. Monti Bragadin:** Writing - review & editing, Visualization. **L. Bonzano:** Writing - review & editing, Visualization. **M.A. Battaglia:** Resources. **M. Bove:** Conceptualization, Supervision, Writing - review & editing. **G. Brichetto:** Conceptualization, Supervision, Project administration, Writing - review & editing. **M. Ponzio:** Methodology, Formal analysis, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. The Dual-task Impact on Daily-living Activities Questionnaire (DIDA-Q) - *Italian version*

Durante la vita di tutti i giorni capita spesso di dover eseguire contemporaneamente due compiti, per esempio camminare e intanto ricordare la lista della spesa da fare. Questo può creare difficoltà che portano a dover camminare più lentamente, o addirittura fermarsi, o a distrarsi da ciò su cui ci stava concentrando.

Indichi con una crocetta quanto per lei è difficile eseguire contemporaneamente le seguenti coppie di compiti.

Indichi quanto per lei è difficile:	Per nulla	Poco	Abbastanza	Molto	Moltissimo
1 Camminare e sorreggere un piatto con del cibo	0	1	2	3	4
2 Camminare e bere da una bottiglietta	0	1	2	3	4
3 Camminare e ricordare il nome di un ristorante, oppure il titolo di un libro o di un film	0	1	2	3	4
4 Camminare e ascoltare un interlocutore che parla	0	1	2	3	4
5 Camminare e organizzare una sequenza di eventi (es. preparare la cena)	0	1	2	3	4
6 Camminare e chiudere la cerniera della giacca	0	1	2	3	4
7 Parlare con qualcuno e camminare su tragitti curvilinei	0	1	2	3	4
8 Camminare e rispondere rapidamente a stimoli visivi (es. fermarsi al rosso, leggere la segnaletica stradale)	0	1	2	3	4
9 Parlare con qualcuno e mantenere l’equilibrio in piedi	0	1	2	3	4
10 Parlare con qualcuno e camminare a velocità sostenuta	0	1	2	3	4
11 Parlare con qualcuno ed effettuare rapidi cambi di direzione	0	1	2	3	4
12 Parlare con qualcuno e camminare a velocità spontanea	0	1	2	3	4
13 Camminare e distinguere i rumori del traffico nella strada	0	1	2	3	4
14 Camminare e tirare fuori qualcosa dalla tasca	0	1	2	3	4
15 Camminare ed effettuare dei conti a mente (es. calcolare il resto di una spesa)	0	1	2	3	4
16 Camminare e cercare un contatto nella rubrica del telefono e/o mandare un sms	0	1	2	3	4
17 Superare un gradino e reggere una borsa	0	1	2	3	4
18 Camminare e articolare un discorso	0	1	2	3	4
19 Camminare e ascoltare della musica o una trasmissione alla radio	0	1	2	3	4

Punteggio:

Arto superiore (MMI): ______ / 24	Funzioni cognitive (MCI): ______ / 32	Funzioni posturali (MCI): ______ / 20	**Totale: ______ / 76**

MMI = motor-motor interference
MCI = motor-cognitive interference

Appendix B. The Dual-task Impact on Daily-living Activities Questionnaire (DIDA-Q) - *English version* (*not validated)*

During everyday life, often we have to execute two tasks simultaneously, such as walking and remembering the shopping list. This may increase the tasks difficulty, leading to the need to reduce gait speed or stop walking, or to deviate from the focus of our attention.

Please, indicate the difficulty level of each of the following combination of tasks.

Please, indicate the difficulty level of the following tasks:	Not difficult	Slightly difficult	Somewhat difficult	Very difficult	Extremely difficult
1. Walking and carrying a plate filled with food	0	1	2	3	4
2. Walking and drinking from a bottle or a can	0	1	2	3	4
3. Walking and remembering the name of a restaurant, the title of a book or of a movie	0	1	2	3	4
4. Walking and listening to someone who is talking	0	1	2	3	4
5. Walking and planning a schedule (e.g., preparing a meal)	0	1	2	3	4
6. Walking and closing the zipper of your jacket	0	1	2	3	4
7. Talking to someone and walking on curvilinear paths	0	1	2	3	4
8. Walking and responding quickly to visual stimuli (e.g., stop at the red light, reading road signs)	0	1	2	3	4
9. Talking to someone and maintaining balance on your feet	0	1	2	3	4
10. Talking to someone and walking at high speed	0	1	2	3	4
11. Talking to someone and performing quick changes of your walking direction	0	1	2	3	4
12. Talking to someone and walking at spontaneous speed	0	1	2	3	4
13. Walking and paying attention to traffic sounds in the street	0	1	2	3	4
14. Walking and getting something out of your pocket	0	1	2	3	4
15. Walking and performing mental arithmetic (e.g., calculating the shopping change)	0	1	2	3	4
16. Walking and using your phone (e.g., looking for a contact, sending a text message)	0	1	2	3	4
17. Going over a step and carrying a bag	0	1	2	3	4
18. Walking and articulating a speech	0	1	2	3	4
19. Walking and listening to music on the radio	0	1	2	3	4

Scoring:

Upper-limb ability (MMI): ______ / 24	Cognition (MCI): ______ / 32	Balance and mobility (MCI): ______ / 20	**Total: ______ / 76**

MMI = motor-motor interference
MCI = motor-cognitive interference

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