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Functional mobility in older women with and without motoric cognitive risk syndrome: a quantitative assessment using wearable inertial sensors

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Background. The Motoric Cognitive Risk (MCR) syndrome is defined in non-demented older adults by cognitive complaints and slow gait. Individuals with MCR are at higher risk of dementia and other poor clinical outcomes, such as falls. However, no data are available as regards functional mobility alterations associated with MCR. The main purpose of the present study is to quantitatively investigate such an aspect using the instrumented Timed-Up-and-Go (iTUG) test carried out using a wearable inertial measurement unit (IMU).

Methods. Fifty-one women aged over 65 years underwent a geriatric and neuropsychologic assessment (which included the Mini Mental State Examination, MMSE and Addenbrooke's Cognitive Examination Revised, ACE-R), instrumented gait analysis and iTUG performed using an IMU located on the lower back. Based on subjective cognitive complaints and slow gait, they were assigned either to the MCR (n = 24) or non-MCR (n = 27) group. IMU data allowed calculation of overall and sub-phases iTUG times.

Results. Women with MCR were characterized by a significantly higher body mass and body mass index, lower normalized handgrip strength, and similar values of MMSE compared to non-MCRs. A trend was observed in terms of lower overall and sub-domain ACE-R score. They also performed iTUG at a significantly slower speed (22.4 s *vs* 14.1 of the non-MCR group, $p < 0.001$) and exhibited increased sub-phase times (29 to 31% higher with respect to non-MCRs).

Conclusions. The findings of the present study suggest that the MCR syndrome impairs functional mobility, probably due reduced muscular strength and coordination, fear of falling and increased instability. The instrumental evaluation of functional mobility appears useful in the management of women with MCR, particularly in monitoring the progression of the motor impairments, verifying the effectiveness of interventions targeted in alleviating the impact on daily life of mobility limitations associated with MCR and in defining tailored rehabilitation programs.

Key words: Motoric Cognitive Syndrome (MCR), Timed-Up-and-Go (TUG), functional mobility, older adults, Inertial Measurement Unit (IMU)

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INTRODUCTION

The motoric cognitive risk (MCR) syndrome was introduced in 2013 [1] to screen older individuals at higher risk of dementia. It is also associated with other poor clinical outcomes in aging, such as disability, cardiovascular disease and falls [2]. The MCR syndrome is defined in non-demented older adults by slow gait and the subjective reporting of cognitive complaints. Thus, being based on the measurement of gait speed, which can be performed with a simple stopwatch, and since it is unnecessary to administer complex cognitive tests MCR allows a fast and easy assessment of the risk of dementia [3] even in contexts of limited availability of resources [4].

Several studies have pointed out that individuals with MCR are at higher risk of falls [2,5,6] and, interestingly, it has been suggested that such risk is specific for the syndrome and not simply originated by the combination of its individual factors (i.e. slow gait and cognitive impairment [2,5]). Although the link between MCR and falls is not completely clear, it has been hypothesized that MCR coexists with decline in musculoskeletal and sensorimotor functions, psychological distress, and ineffective coping styles, all factors somehow recognized as associated with risk of falls [2]. Such issues appear of particular concern in women, as it has been observed that they are more exposed to the risk of falls [7] and are likely to suffer more severe consequence in terms of injuries associated to non-fatal falls [8].

The increased risk of falls reflects, among other factors, a certain degree of impairment in functional mobility [9] and thus it would be of interest to use complementary quantitative tools suitable to assess it. This would support a better understanding the clinical phenotype of MCR, given that slow gait and cognitive complaints may relate to multiple dimensions of mobility. In this regard, the instrumented version of the Timed-Up-and-Go test [10] (TUG) might make a useful contribution by providing additional information concerning the motor phenotype associated with MCR. The TUG is a clinical test widely employed in clinical settings to assess functional mobility and risk of falls in community-dwelling and frail older adults [11-13]. In recent years its instrumented version, known as "iTUG", which exploits the possibilities offered by wearable inertial measurement units (IMUs, devices composed of an accelerometer, gyroscope and magnetometer) has been proposed with encouraging results. In particular, the main advantage of iTUG is that the results are not limited to the overall time required to perform it, but also include time, speed and accelerations associated with each TUG sub-phase, namely sit-to-stand, intermediate and final 180° turns and stand-to-sit [14-16]. Such a large and detailed dataset allows the definition with great accuracy of which phases (and to what extent) are compromised and thus infer whether functional mobility is impaired by factors associated with muscular strength, coordination, gait, or postural control.

Based on the aforementioned considerations, in this study we employed the iTUG to quantitatively characterize functional mobility in women with and without MCR, to explore the different components of functional mobility associated with the motor phenotype of MCR.

METHODS

Participants

From November 2019 to February 2020, 51 women aged over 65 (mean age 77.9 ± 5.2 years, height 155.6 ± 5.9 cm, body mass 60.3 ± 10.4 kg) consecutively examined at the Center for Cognitive Disorders and Dementia (in collaboration with the Geriatric Unit, "SS. Trinità" General Hospital, Cagliari, Italy) were enrolled in the study. They were unaffected by dementia, neurologic disorders that interfere with mobility (e.g. Parkinson's disease, multiple sclerosis and stroke), severe symptomatic orthopedic conditions and were able to walk without walking aids. After a detailed explanation of the purposes and methodology of the study, they signed an informed consent form. The study was carried out in compliance with the ethical principles for research involving human subjects expressed in the Declaration of Helsinki and its later amendments and was approved by the local ethics committee (ATS Sardegna authorization number 300/2020/CE).

Neuropsychological and geriatric assessment

At first, participants underwent a detailed geriatric and psychological assessment which included:

- cognitive status evaluation, performed by means of the Italian version of the Mini Mental State Examination [17,18] and Addenbrooke's Cognitive Examination Revised [19,20] (ACE-R). In the latter tool, the analysis is carried out across five cognitive domains, namely attention and orientation, memory, verbal fluency (related to cognitive abilities of the executive function), visuospatial, and language. The overall score ranges from 0 to 100, with lower scores indicative of greater cognitive impairment;
- self-report assessment of depression, carried out through the Italian version of the Short Form Geriatric Depression Scale [21] (GDS);
- questionnaires on Activities of Daily Living (ADL) and Instrumental ADL [22,23];
- handgrip strength (HGS) using a validated [24] digital

hand dynamometer (DynEx, MD Systems, Westerville OH, USA) previously employed in studies involving older adults [16]. The HGS representative of a certain participant was obtained as the maximum value of six trials (three for each limb, alternated and interspersed by 20s of rest). To take into account possible differences in body mass of the groups, we applied an allometric normalization of the HGS value [25] using the equation

$$nHGS = \frac{HGS}{m^{0.63}}$$

in which nHGS represent the normalized strength, HGS the absolute strength (kg_f), m the individual's body mass (kg) and 0.63 the allometric exponent.

Instrumental assessment of gait and functional mobility

Both gait and functional mobility were quantitatively assessed using a single wearable inertial sensor (G-Sensor®, BTS Bioengineering S.p.A., Italy) previously employed in similar investigations on older adults [16,26,27] and individuals with neurologic disorders [28]. The sensor was attached to the participant's trunk using a semi-elastic belt, in two different positions, which approximately corresponded to S1 vertebrae (for gait analysis) and L1 vertebrae (for TUG test) locations. Such positions, which were recommended by the manufacturer of the device, are among those commonly employed to assess gait and posture in older adults [29-30].

To quantitatively assess gait patterns, participants were requested to walk along a 30-m hallway, following a straight trajectory at a self-selected speed. During the trial, the inertial sensor acquired the acceleration values along three orthogonal axes: antero-posterior (AP which corresponds to the walking direction) medio-lateral (ML), and supero-inferior (V) at 100 Hz frequency. Data were transmitted in real-time via Bluetooth to a notebook, where they were later processed using a custom Matlab® routine (available on request) to calculate gait speed. Speed values were subsequently employed to define the inclusion of the participants in the MCR group according to the following cut-off values [1]:

- age 70-74 years: speed ≤ 0.778 m s^{-1}
- age 75-79 years: speed ≤ 0.714 m s^{-1}
- age 80-84 years: speed ≤ 0.662 m s^{-1}
- age 85 years or older: speed ≤ 0.575 m s^{-1}

Functional mobility was assessed using the iTUG test. To this end, participants were requested to sit with arms crossed at the wrists and held against the chest on a standard office chair without armrests (seat height and width 48 cm, seat depth 40 cm) equipped with a back support 34 cm high. At the "start" signal, they stood up, walked for 3 m at a comfortable and safe speed [10], performed a 180° turn around a cone, walked back to the chair and performed a second 180° turn to sit down and end the test. Data acquired by the wearable sensor during the trial were transmitted via Bluetooth to a notebook, where dedicated software (BTS G-Studio®, BTS Bioengineering S.p.A., Italy) automatically segmented the task, on the basis of the acquired accelerations and angular velocities, into the following sub-phases:

Table I. Demographic, anthropometric and clinical features of the participants. Values are expressed as mean ± SD.

		Non-MCR	MCR	P-value
Demographic and anthropometric	**Participants #**	27	24	
	Age (years)	77.8 ± 5.2	78.1 ± 4.8	0.833
	Height (cm)	155.4 ± 5.1	155.8 ± 6.8	0.801
	Body Mass (kg)	55.8 ± 9.6	65.4 ± 9.1	< 0.001*
	Body Mass Index (kg m^{-2})	23.1 ± 3.3	27.0 ± 3.5	< 0.001*
Handgrip strength	**Absolute value (kg_f)**	14.0 ± 4.1	13.2 ± 4.3	0.483
	Normalized value (kg_f kg^{-1})	1.1 ± 0.3	0.9 ± 0.3	0.020*
Cognitive measures	**MMSE**	26.9 ± 3.3	26.1 ± 3.3	0.364
	ACE-R (overall)	78.7 ± 13.4	70.0 ± 15.3	0.063
	ACE-R attention/ orientation	17.0 ± 2.1	16.3 ± 2.2	0.277
	ACE-R memory	15.8 ± 6.9	13.7 ± 6.1	0.258
	ACE-R fluency	8.0 ± 2.8	5.9 ± 2.9	0.034
	ACE-R language	23.8 ± 2.8	22.0 ± 3.6	0.052
	ACE-R visuospatial	14.2 ± 2.2	12.0 ± 3.6	0.047

MCR: Motoric Cognitive Risk; MMSE: Mini Mental State Examination; ACE-R: Addenbrooke Cognitive Examination (Revised); the symbol * denotes a statistically significant difference *vs* Non-MCR group after Bonferroni correction

sit-to-stand (transition from sitting to standing position), intermediate 180° turn (which inverts the walking direction), final 180° turn (which prepares the body for the descent towards the sitting position) and stand-to-sit (transition from upright to sitting posture). The overall iTUG time and the times associated with each sub-phase were used for the subsequent analysis.
Participants performed two trials of both gait and iTUG tests while wearing their usual clothes and shoes. The first one was administered to let the participants to familiarize with the task and the presence of the device on their bodies, while during the second one the trunk acceleration signals were actually acquired.

Statistical analysis

Parametric statistical analysis was adopted after preliminary tests for normality (using the Shapiro-Wilk test) and homogeneity of variances (Levene's test) were carried out. The existence of possible differences in iTUG parameters originated by the presence of the MCR syndrome was explored using the one-way multivariate analysis of covariance (MANCOVA), where the independent variable was the group (MCR/non-MCR), the dependent variables were the 5 TUG parameters previously listed and the covariates were age and body mass index. One-way MANOVA was also carried out to detect differences in the overall and cognitive domains (i.e. MMSE, ACE-R overall and 5 ACE-R sub-domains), anthropometric features and cognitive scores. The level of significance was set at $p = 0.05$ and the size effect was assessed using the eta-squared (η^2) coefficient. Univariate ANOVAs were carried out as a post-hoc test by reducing the level of significance to $p = 0.01$ (0.05/5) for iTUG parameters, $p = 0.007$ (0.05/7) for cognitive performance scores and $p = 0.0125$ (0.05/4) for anthropometric features, after a Bonferroni correction for multiple comparisons. All analyses were performed using the IBM SPSS Statistics v.20 software (IBM, Armonk, NY, USA).

RESULTS

Of the 51 women considered eligible for the study, 24 (47%) met MCR criteria characterized by a gait speed slower than the cut-off values previously listed, and reported subjective cognitive complaints based on their answer to item 10 of the Italian version of the Short Form of the GDS ("Do you think you have more problems with memory than most people?"). The remaining 27 participants were considered as non-MCR. Their main demographic, anthropometric and clinical features are reported in Table I.
The statistical analysis indicated a main group effect as regards the demographic/anthropometric features $[F(4,46) = 4.03, p = 0.007, \text{Wilks } \lambda = 0.74, \eta^2 = 0.26]$ and the post-hoc analysis showed that the significant difference involved body mass and body mass index (BMI) which were found higher in the MCR group, $p < 0.001$ in both cases). In contrast, MANOVA failed in detecting a main effect of group in terms of cognitive performance $[F(7,43) = 2.14, p = 0.06, \text{Wilks } \lambda = 0.74, \eta^2 = 0.26]$. Lastly, a significant difference was found in terms of normalized HGS (lower in the MCR group, $p = 0.02$).
The results of the instrumental TUG analysis are reported in Table II and graphically illustrated in the diagrams of Figure 1.
A significant main effect associated with the presence of the MCR syndrome was detected by MANCOVA as regards functional mobility $[F(5,43) = 4.79, p = 0.001, \text{Wilks } \lambda = 0.64, \eta^2 = 0.33]$. In particular, the post-hoc analysis revealed that both overall and sub-phase TUG times, with the exception of the stand-to-sit time, were significantly higher in the MCR group. The largest difference between the groups was found in overall iTUG time (37% higher in MCR, $p < 0.001$), while similar increases (in the range 29 to 31%) were observed for the sit-to-stand and 180° turn phases.

Table II. iTUG parameters measured with the inertial sensor. Values are expressed as mean ± SD.

	Non-MCR	MCR	P-value
iTUG Duration (s)	14.15 ± 2.61	22.39 ± 7.55	< 0.001*
Sit-to-Stand Time (s)	1.81 ± 0.57	2.63 ± 1.15 *	0.003*
Intermediate 180° Turn Time (s)	2.68 ± 0.89	3.84 ± 1.49 *	0.001*
Final 180° Turn Time (s)	2.06 ± 0.79	2.9 ± 1.09 *	0.007*
Stand-to-Sit Time (s)	1.08 ± 0.36	1.55 ± 0.86	0.006*

MCR: Motoric Cognitive Risk; TUG: Timed Up and Go, the symbol * denotes a statistically significant difference *vs* Non-MCR group after Bonferroni correction ($p < 0.01$)

DISCUSSION

General considerations

The main purpose of the present study was to compare functional mobility performances of women with and without MCR, using the instrumented version of TUG. The results support the hypothesis of MCR being associated with alterations that are not limited to walking, but extend to other dimensions of mobility, as those present in the TUG tests, which require a combination of strength, balance and coordination.

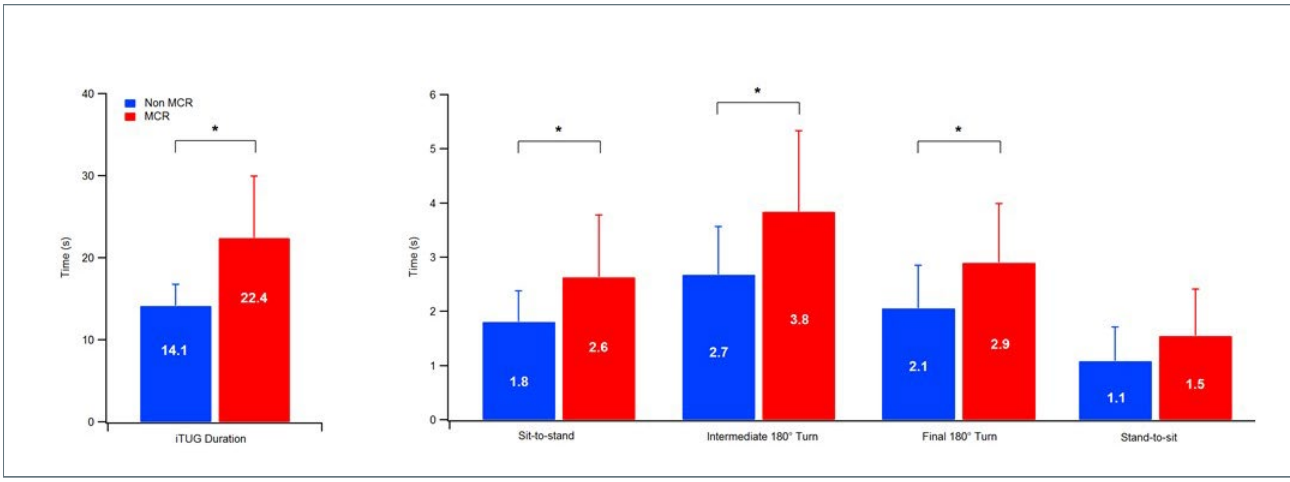

Figure 1. Bar diagrams of iTUG parameters across the tested groups: blue bars indicate individuals without MCR and red bars individuals with MCR. Error bars indicate standard deviation. The symbol * denotes a statistically significant difference after Bonferroni correction ($p < 0.01$).

First, we must highlight the clinical characteristics of our sample, especially the high prevalence (47%) of MCR, while the previous studies report a prevalence of MCR around 10% [31,32]. To explain such an apparent discrepancy, we point out that our recruitment was carried out at a clinical center specialized in cognitive disorders and dementia: every older individual referred to the center needs to have a screening geriatric and/or a neuropsychologic consult by their family physician, and the individuals who fail this first screening will have a comprehensive neuropsychological assessment. Thus, it is not surprising that an important proportion of the women evaluated at our center did present cognitive complaints and may be at the very last stage before dementia. By contrast, the majority of studies on MCR enroll community-dwelling older adults who are thus expected to be healthier. Women with MCR included in our sample featured a higher body mass and BMI and most were overweight or obese (67 and 21% respectively) while in the non-MCR group 33% were overweight and not obese. Such findings were also reported in previous studies [5,33] and confirm that obesity is a risk factor for MCR [31,33,34]. Finally, it is to be noted that even though the MMSE score was very similar in the two groups, we observed a trend towards lower ACE-R scores (generalized in all sub-domains but close to statistical significance for the visuospatial and fluency domains) in women with MCR, thus suggesting the possibility of different cognitive profiles in the two groups, a fact that has been reported in previous studies [36].

Our results show that individuals with MCR exhibit a poorer performance in terms of overall iTUG duration, which results from a combination of increased times necessary to perform all sub-phases. This suggests that the longer time needed to complete the task in MCR is not only originated (although certainly mainly driven) by the slow gait but is also associated with other dimensions of mobility. We will separately discuss the TUG sub-phases below.

Sit-to-stand

Previous studies on older adults pointed out that the ability to efficiently perform a sit-to-stand transition depends on a combination of factors including, among the most relevant, lower limb strength (in particular that of knee extensors) and self-reported fear of falling [37,38]. Although we collected no data on lower limb strength, we observed a significant lower HGS in women with MCR, once the allometric normalization was applied. This was because even though the absolute result of the HGS test was similar across groups, women with MCR were characterized by higher values of body mass and BMI (a fact already observed in previous studies [5]). Regarding fear of falling, several previous studies reported that in individuals with MCR the relative risk of falls is significantly increased [39] and thus they may adopt a more cautious approach during the sit-to-stand transition to unconsciously reduce the chance of a loss of balance. The combination of these two aspects, namely reduced muscular strength/power and increased fear of falling, may thus explain the longer times required to perform the task.

180° turns

Several studies investigated the strategies adopted to perform 180° turns in older adults either healthy or affected by neurologic diseases [40,41]. This resulted in the development of scales and clinical measures to describe difficulties encountered in turning on the basis of variables such as number of steps taken during the turn and overall time

taken to accomplish the turn [40,42]. Such an approach has been found useful in discriminating between healthy and impaired older adults and demonstrates a good sensitivity for identifying multiple fallers. Moreover, instrumental studies using three-axial accelerometers [43,44] showed that individuals at higher risk of falls exhibit increased turning time and require more steps to complete the task.
Even in this case, muscular strength (particularly at ankle level) represents a critical factor that influences the task execution, as the asymmetrical nature of the task requires relevant propulsion forces to be generated by the ankle plantar-flexors, especially as regards the outer limb [45]. This is also partly consistently confirmed by the fact that physical activity programs targeted to increase lower limb strength have been reported effective in improving turning performance [46]. Another factor that may contribute to causing poor performance during turning in women with MCR is represented by impaired balance [47]. In this regard, it is noteworthy that individuals with MCR reported low scores in the activities-specific balance confidence scale [48] thus indicating that they perceive instability in a range of daily activities. This may justify a very cautious approach to all those tasks (like turning) that challenge postural control.

Stand-to-sit

Although the differences between MCRs and non-MCRs in this task did not reach statistical significance, they were of the same order of magnitude with respect to the other iTUG sub-phases. It is noteworthy that stand-to-sit is probably the least investigated postural transition among those commonly performed in daily life, but few studies using accelerometers have reported that in older adults, either physically unfit (i.e. frail) or affected by neurologic conditions, this task is characterized by significant differences in terms of duration and trunk accelerations/displacements in comparison to healthy individuals [49-51].
Concerning our findings, it is reasonable to hypothesize that women with MCR exhibit what has been defined by Parvaneh et al. [51] as "cautious sitting", that is, a stand-to-sit transition characterized by abnormal longer postural adjustment and preparation for sitting which follows (as previously discussed) a longer 180° turning and a standing pause. Such a strategy is probably due to a combination of factors which include impaired postural control, reduced strength of the knee flexors and fear of falling [51].

Limitations of the study

Some limitations of the study need to be acknowledged. First, the sample was composed exclusively of women and, since it has been reported that sex-related differences exist in terms of TUG performance [52], the generalization to men is not possible. Moreover, due to the relatively small number of participants, we did not include among the covariates relevant factors such as education, which are associated with mobility [53-55].

Conclusions

The present study investigated functional mobility in women with and without MCR in a clinical setting using the instrumented version of TUG carried out using a wearable inertial sensor. As such a device provides detailed information on each TUG subphase, it is possible to accurately define which aspects of mobility are more affected by the presence of MCR. The results indicate that MCR impacts the various iTUG sub-phases, thus suggesting that the syndrome impairs functional mobility through the combination of several factors, including reduced muscular strength and coordination, fear of falling and increased instability.
Based on these findings, it is possible to state that the instrumental evaluation of functional mobility appears useful in the integrated management of people with MCR, particularly in monitoring the progression of the motor impairments, verifying the effectiveness of interventions aimed at alleviating the impact on daily life of mobility limitations associated with MCR, as well as in defining tailored rehabilitation programs. Future studies should evaluate if MCR participants associated with poorer functional mobility performances using the iTUG, are at higher risk of developing dementia.

Ethical consideration

All procedures involving human participants were conducted in accordance with the 1964 Helsinki Declaration and its later amendments. Informed consent was obtained from all individual participants included in the study.

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Conflict of interest

The Authors declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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