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# Investigating the Construct Validity and Reliability of the Test of Motor Competence Across Iranians' Lifespan

**Sedigheh Salami[1], Paulo Felipe Ribeiro Bandeira[2], Fatemeh Sohrabi[1], Parvaneh S. Dehkordi[1], Clarice Martins[3], Michael J. Duncan[4], Louise L. Hardy[5], Amir Sham[6]**

1. **Department of Motor Behaviour, Faculty of Sports Sciences, Alzahra University, Tehran, Iran**
2. **Department of Physical Education, Universidade Regional do Cariri, Crato, Brazil**
3. **Research Centre in Physical Activity, Health and Leisure, University of Porto, Portugal**
4. **Centre for Sport, Exercise and Life Sciences, Coventry University, UK**
5. **Prevention Research Collaboration, School of Public Health, University of Sydney, Australia**
6. **Motor Behaviour Department, Sports Sciences Research Institute (SSRI) of Iran, Tehran, Iran.**

**Corresponding Author: Louise L. Hardy, Prevention Research Collaboration, School of Public Health, University of Sydney, Australia. Email: louise.hardy@sydney.edu.au**

## Abstract

Motor competence (MC) has been extensively examined in children and adolescents, but has not been studied among adults nor across the lifespan. The Test of Motor Competence (TMC) assesses MC in people aged 5-85 years. Among Iranians, aged 5-85 years, we aimed to determine the construct validity and reliability of the TMC and to examine associations between TMC test items and the participants' age, sex, and body mass index (BMI). We conducted confirmatory factor analysis (CFA) to evaluate the TMC's factorial structure by age group and for the whole sample. We explored associations between the TMC test items and participant age, sex, and BMI using a network analysis machine learning technique (Rstudio and qgraph). CFA supported the construct validity of a unidimensional model for motor competence for the whole sample (RMSEA = .003; CFI = .998; TLI= .993) and for three age groups (RMSEA<.08; CFI and TLI> .95). Network analyses showed fine motor skills to be the most critical centrality skills, reinforcing the importance of fine motor skills for performing and participating in many daily activities across the lifespan. We found the TMC to be a valid and reliable test to measure MC across Iranians' lifespan. We also demonstrated the advantages of using a machine learning approach via network analysis to evaluate associations between skills in a complex system.

**Keywords** Lifespan, Machine learning, Motor competence, Network perspective.

## Introduction

Motor competence (MC) refers to the degree of an individual's ability to perform a wide range of motor skills proficiently, including quality of movement, motor coordination, and motor control (T Utesch & Bardid, 2019). MC has been extensively examined in children and adolescents (Lopes et al., 2021), and research evidence suggests that MC is associated with positive health outcomes, including physical activity (S. W. Logan, Webster, Getchell, Pfeiffer, & Robinson, 2015), physical fitness (Cattuzzo et al., 2016), and improved weight status (L. Barnett et al., 2016). Systematic reviews have also found that age, sex, and body mass index (BMI) are correlated with childrens' and adolescents' MC (L. Barnett et al., 2016; Lubans, Morgan, Cliff, Barnett, & Okely, 2010). While MC has been extensively examined in children and adolescents, information on adults' MC and on MC across the lifespan is unavailable (Nesbitt et al., 2018). Globally, the proportion of people aged >60 years is predicted to double from 12% to 22% between 2015 and 2050 (Rudnicka et al., 2020). The age shift in population demographics is an emerging public health concern that requires strategies to foster healthy ageing, particularly to improve physical functioning so that older people can continue to perform many activities of daily living and maintain their independence.

Historically, tests of MC were developed to screen children with delayed motor development (Cancer, Minoliti, Crepaldi, & Antonietti, 2020). However, because of the global rise of inactivity (Kohl 3rd et al., 2012) MC tests have been adopted to examine

MC epidemiology (i.e., prevalence, distribution, trends, determinates, correlates) among healthy developing children. Population studies have been limited and primarily conducted in high income countries, but the evidence to date shows children's MC levels to be suboptimal, with some evidence of secular declines (Lopes et al., 2021). These findings have driven interventions to improve children's MC as a strategy to ameliorate children's inactivity (S. Logan, Robinson, Wilson, & Lucas, 2012). Meanwhile, as noted above, comparable epidemiological information on adults' MC is lacking.

There is no consensus regarding any gold standard test of MC, and investigators' choices of MC tests have varied across countries, geographical regions, and cultures, hindering international comparisons and cross-cultural understandings of differences in motor development. Among several studies of children's MC, there have appeared to be cross-cultural differences (Bardid, Rudd, Lenoir, Polman, & Barnett, 2015; L. M. Barnett et al., 2019; Brian et al., 2018; Chow, Henderson, & Barnett, 2001; Flôres, Rodrigues, Luz, & Cordovil, 2021; Laukkanen et al., 2020; Luz et al., 2019; Ma, Duncan, Chen, Eyre, & Cai, 2022; Ruiz, Graupera, Gutiérrez, & Miyahara, 2003). Whether these differences reflect varied geo-cultural practices, or the cultural sensitivity of various MC tests is equivocal. However, these findings suggest a need for a universally accepted and culturally validated test of MC to better understand cross-cultural influences of MC.

MC tests assess different aspects of movement quantitatively and qualitatively (S. W. Logan, Barnett, Goodway, & Stodden, 2017). Quantitative tests measure the product of movement (e.g., time, distance, speed) and test scores are typically compared to a normative group and can be transformed into standard scores (e.g., z-scores) or percentiles to allow individual examinees to be compared to age-sex peers. The advantages of quantitative (or product-oriented) tests are that their administration method is standardized and they are generally easy and inexpensive to administer to large groups. Qualitative tests measure the proficiency of movement according to a set of criteria on how a movement should be performed and are useful for informing pedagogical approaches for MC interventions. Limitations of qualitative or process-oriented tests are that they generally require specialist training, are time intensive to administer, and present inter-rater reliability concerns, making them poorly suited for large groups.

While motor development is a continuous process (Goodway, Ozmun, & Gallahue, 2019), there is a paucity of tests to assess and monitor MC in healthy developing individuals across the lifespan. MC tests for children and adolescents are not necessarily appropriate for adults. For example, most children's qualitative MC tests assess sport-related skills and athletic ability to determine stages of specific proficient movements. Furthermore, in normal development, as children age, MC improves (L. Barnett et al., 2016); this makes children's qualitative assessments subject to ceiling effects and unable to differentiate proficiency in older children and adults. Quantitative tests hold greater promise to objectively assess and monitor MC across the lifespan, but ageing effects on changes in MC is currently unclear in light of age-related changes in brain function and the neuromuscular system that are first associated with improving skills into early adulthood and then associated with older adults' deficits in proprioception, balance, gait, increased reaction time and the ability to control and execute movements (Seidler et al., 2010). Very few studies have examined MC among adults, and none have shared consistent measurement instruments. Evidence in adult populations has not always shown measures of functional capacity (e.g., walking speed, supine-to-stand, timed up and go) in older adults to be linked to health-related outcomes, physical independence, mortality, and overall quality of life (Corsonello et al., 2012; Rikli & Jones, 2001; Smee, et al., 2012; Volpato et al., 2011). Other investigators have shown that brain aging disrupts the neural integrity of motor outputs, reduces some neuropsychological abilities, and is linked to an increased risk of falls in older adults (Kovacs, 2005). The financial, morbidity, and mortality burdens associated with falls are substantial (James et al., 2020). The evidence indicates MC in many children and adolescents is sub-optimal and has declined over time (Lopes et al., 2021). It is not known what impact this may have on their future adult MC. Gathering epidemiologic evidence on MC across the lifespan is required to determine any potential generational shifts and guide preventative interventions.

Norwegian researchers (Sigmundsson et al., 2016) have recently addressed the need for a simple universal MC test that can be administered across the lifespan. The Test of Motor Competence (TMC) is suitable for people aged 5-85 years; it is a quantitative test, designed to assess MC through tasks required for activities of daily living (Sigmundsson, Lorås, & Haga, 2016). This approach allows MC to be examined as a function of age. The TMC assesses two fine motor tasks, based on manual dexterity, and two gross motor tasks, based on dynamic balance. Each task is timed, and the sum of the times on the separate tasks is transformed into standardized scores (i.e., TMC z-scores). The TMC is a simple low-cost test to administer, making it feasible for testing large groups. To date, the TMC has only been psychometrically researched in a Norwegian population (Sigmundsson et al., 2016). As Iran is the fifth largest country in Asia, with a population of approximately 85 million, and it has significant cultural and geographical differences from Norway which is a Western high-income country. Thus, it is necessary to study the TMC within an Iranian population to examine the specificities of different environmental, social, and cultural influences across population groups and to ascertain the TMC's validity and cross-cultural psychometrics (Hulteen, True, & Pfeiffer, 2020; Robinson et al., 2015)

The construct validity of the TMC has only been established by a reliance on movement skill literature; it has not yet been subjected to statistical analyses for a determination of the presumed singular dimensionality of its composite scores. Motor assessments generally adopt a composite score based on various subskill performances presumed to indicate overall motor competence. Thus, the use of a single score assumes that MC is a unidimensional construct based on a hypothesis of underlining general motor ability (Brace, 1927; Hands, McIntyre, & Parker, 2018). The dimensionality of this underlying theoretical construct is not fully understood; since models with $< 3$ variables can cause measurement problems, and models with $\geq 3$ variables require testing to be sure a unidimensional construct is a good fit of the model. Since the TMC used two subscales with two variables (Sigmundsson et al., 2016), the TMC should be unidimensional due to the limited number of variables.

Confirmatory factor analysis (CFA) is a common statistical method to test an instrument's internal consistency and factor structure. However network analysis is an additional statistical approach to graphically and quantitatively model complex patterns of associations among variables within a system (Schmittmann et al., 2013). Network psychometry is a novel approach to evaluate complex systems such as MC and related constructs. The network analysis approach enables researchers to explore the role of each variable within the system in relation to measures of centrality to discover which variables have the strongest associations and may be more sensitive to changes from interventions. A machine learning approach to the network analyses graphically presents the association of multiple interactions between variables (Borsboom et al., 2016; Epskamp & Fried, 2018). Applying machine learning through network analysis to this study, the established correlates of MC in children and adolescents (i.e., age, sex, BMI) comprise a nonlinear system in which all the underlying mechanisms interact to form an emerging pattern to identify the most important MC factors within the network.

To date, only two studies (Bandeira et al., 2020; Duncan et al., 2022) have applied machine learning through network analysis to explore the psychometric properties of one of the most common MC tests in children (i.e., Test of Gross Motor Development, (Ulrich & Sanford, 1985). The authors of these studies suggested that network models are useful tools for measuring dynamic and complex systems such as MC. To our knowledge, no study has considered the network analysis approach in the context of MC across the lifespan. In this study, using CFA and machine learning through network analysis, we had two goals: (a) to examine the internal reliability and construct validity of the TMC as a developmental measure of MC across the lifespan and (b) to investigate the association between biological factors (age, sex, and BMI) and TMC test items.

## Method

### *Participants*

For CFA studies, a sample size of 500 participants is considered very good for confidence in the results (Kyriazos, 2018). For this study, 500 Iranians aged 5-85 years volunteered. School children aged 5-18 years (n = 234; 64% female) were selected using multi-stage stratified cluster sampling methods. First, the city of Tehran was divided into four main geographies: north, south, east, and west (stratified sampling). From each main geographic region, two districts were randomly selected (cluster sampling) and children between 5-18 years old (n=234) were identified from kindergartens (n=10), preschools (n=9), primary (n=6) and high schools (n=9). Adults aged 18-85 years ($n$ = 266) were randomly selected in the north and east of Tehran's main geographies and were recruited from universities (n=2), parks (n=12), and aged care homes (n=3). Participants were eligible to participate if they had no behavioral problems or ankle fractures in the past year (children), or no orthopedic defects (adults).

This study was approved by xxxx (IR.SSRI.REC.1399.729). Participants were provided with written information about the purpose and nature of the study, and we obtained verbal assent and/or written informed consent form from the participants and/or parents/ guardians of children aged 5-18 years prior to their study involvement. Participants could withdraw from the study at any time.

***Procedure***

Testing was conducted in a sports hall by four researchers trained in the administration of the TMC. The participant's age, sex, height (m), and weight (kg) were recorded, and their BMIs (kg/$m^2$) were calculated prior to the TMC assessment. Participants were assessed individually, and the order of testing was fine motor skills and then gross motor skills. The researchers explained and demonstrated each skill before the assessment, and the participants were allowed one practice attempt for each skill. Each assessment took approximately 10-minutes per person. For each TMC task, participants' performance was measured by a stopwatch and recorded in seconds. The original form of the TMC as applied in Norway (Sigmundsson et al., 2016) had an acceptable internal consistency, as all individual test item scores correlated positively with the total score. Correlations ranged from .48 to .64; the Cronbach's alpha value for the standardized test items was 0.79, which can be considered as acceptable. The TMC has a construct validity of 0.47 to the MABC for 7-8 year old children ($n$ = 70) and a test–retest coefficient for the total score of 0.87 (Sigmundsson et al., 2016).

***TMC Fine Motor Tasks***

***(1) Placing Bricks (PB***). This subtest required 18 square shaped Duplo™ bricks to be placed on a Duplo™ board as fast as possible. The participant was seated at a table and given a practice run before the testing. The bricks were positioned in horizontal rows of three on the side of the active hand and the board held firmly with the other hand. Both hands were tested.

***(2) Building Bricks (BB).*** This subtest required participants to build a "tower" as quickly as possible with 12 square shaped Duplo™ bricks. Participants held one brick in each hand. At a signal, the participant assembled the bricks together one after the other, until all 12 were put together to form a tower. Arms were not allowed to rest on the table. The bricks were held in the air all the time. Participants sat at a table, and the time was stopped when the participant released the last brick.

***TMC Gross Motor Tasks***

***(3) Heel-to-toe walking (HTW).*** This test required participants to walk a straight line (4.5 meters long) as fast as possible, placing heel against toe in each step.

***(4) Walking/running in slopes (W/R).*** This subtest required participants to walk/run from the starting point, as fast as possible, in a figure eight form, around two marked lines (1m in width). Line 1 was 1 meter from the starting point and Line 2 was 5.5 meters from the starting point. If the participants start on the right side of Line 1, they go to the left side of Line 2, turn around, and go back on the right side of Line 2 and left side of Line 1, and return to the starting point. Completion time was measured when the participant arrived at the starting point. Participants freely chose which direction they walked/ran.

***Data Analysis***

Data were analyzed using SAS Version 9.4 (SAS Inst., Cary, NC, USA). Participants were stratified into three age groups for the analyses: 5-10 years (children; n = 100), 11-18 years (adolescents; n = 134), and 18-85 years (adults; n = 266). Descriptive statistics (means, standard deviations) were calculated to describe the four TMC tasks and total TMC z-score, by sex and age groups.

We conducted a CFA to evaluate the factorial structure of the TMC by age group and for the whole sample. The robust maximum likelihood estimation (MLR) method was used. General fit indexes ($\chi^2$), comparative fit index (CFI), Tucker Lewis

(TLI) and mean square approximation error (RMSEA) were used to evaluate the unidimensional model. Values >.90 were considered a minimum value to infer model fit for CFI and TLI (Hu & Bentler, 1999) while RMSEA values from .0 to .08 were considered acceptable (Byrne, 2013). We set statistical significance at $p$ <.05. Data were analyzed in Mplus 8.0 (Muthén, Muthén, & Asparouhov, 2017).

We evaluated the internal reliability of the TCM using composite reliability (CR), which is considered a measure of internal consistency of scale items and a structural quality indicator. The calculation of composite reliability was performed from the parameters estimated by the analysis of structural equations of the CFA. Composite reliability values >0.60 were considered acceptable (Hair, Black, Babin, & Anderson, 2009).

The pattern of the associations between TMC test items and biological variables of age, sex, and BMI were evaluated using the network analysis machine learning technique. In terms of test validation, network analysis presents a graph to represent the multiple associations between variables, considering all the complexity of their inter-relationships (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012) 2012). We used Rstudio and qgraph software to calculate and visualize the network and to present the graph in relative space where the variables with the highest association remain together and those with the weakest associations are pushed apart (Fruchterman & Reingold, 1991). We used Pairwise Markov random models to improve the accuracy of the partial correlation network, which were estimated from the regular regression of the L1 neighborhood (Hastie, Tibshirani, Friedman, & Friedman, 2009). The Extended Bayesian Information Criterion Index (EBIC) parameter were adjusted to 0.5 to create a network with greater parsimony and specificity (Foygel & Drton, 2010).

The role of each variable in the network was assessed from the centrality measures, using three measures: (a) Betweenness was estimated from the number of times that the node was part of the shortest path among all other node pairs connected to the network; (b) the closeness index was determined from the inverse of distances from one node to all others; and (c) the strength centrality indicator was the sum of all path weights that connected one node to another (Epskamp & Fried, 2018). Variables with higher betweenness values are considered more sensitive to changes and may act as a hub, connecting other pairs of variables in the network. A variable with a high closeness value will be quickly affected by changes in any part of the network and may also affect other parts. The strength indicator is essential to understand which variables present the most robust connections in the current network pattern. In the graphs, positive relationships are expressed by blue color and negative relations by red color; the thickness of the graph indicates the weight of the association.

## Results

Table 1 illustrates the characteristics of our participant sample of 500 Iranians aged 5-85 years (64% female, 36% male; $M_{age}$ = 24.1 years, *SD* = 17.1 years; $M_{\text{BMI}}$ = .98 kg/m$^2$, *SD* = 4.97).

[Insert Table 1 about here.]

***Confirmatory Factor Analysis and Reliability***

Table 2 shows that the general adjustment indices for the one-dimensional TMC model had excellent general fit indices, with all CFI and TLI >.90 and RMSEA <.08 for each of the three age groups and for the whole sample. Table 3 shows that the individual adjustment indicators for each TMC test had factor loadings >.30 and were significant for each age group and the whole sample. The composite reliability values were >.60 and considered adequate for each age group and for the whole sample.

[Insert Tables 2 and 3 about here.]

***Network Analysis/ Associations***

The network analysis weights matrix is shown in Table 4. Age had a strong positive association with Walking/Running in slopes (r = .44) and was negatively associated with Building Bricks (r = -.14) and Heel-to-toe walking (r = -.19). Based on the relative magnitudes of correlations in the network analysis, males performed better than females on Placing Bricks (r = .37). BMI was positively associated with age (r = .58) and Walking/Running in slopes (r = .23) and BMI was negatively associated with

Placing Bricks (r = -.18), Building Bricks (r = -.26), and Heel-to-toe walking (r = -.22). Figure 1 shows the graph for these network associations, with positive associations in blue and negative associations in red. The thickness of the line indicates the weight of the ratio.

[Insert Table 4 and Figure 1 about here.]

### ***Centrality Measures***

The results of the network centrality are presented in Table 5. Placing Bricks and Building Bricks had the highest values of Betweenness (.953 and .953, respectively), Closeness (1.513 and .682, respectively) and Strength (1.459 and .983, respectively). The centrality of these motor skills was greater than for the other motor skills in the network.

## Discussion

Our purpose in this study was to use a network analysis approach to examine reliability and construct validity of the TMC as a developmental measure of MC across the lifespan among Iranians aged 5-85. Years. This is the first study to examine the psychometric properties of the TMC using a lifespan perspective. In general, test instruments of this kind have been only as valid as the proposed theoretical constructs on which they are based (Burton & Miller, 1998), and that theoretical assumption, in this case, traces to Brace (1927) who proposed in the General Motor Ability (GMA)

Hypothesis that motor abilities are highly correlated and can be grouped together as a single, unidimensional construct). This concept was challenged by Henry in the 1960s who posited in the Specificity of Motor Ability Hypothesis (Henry, 1961) that correlations between motor skills are weak, and, therefore, motor abilities are independent. Recently, there has been a renewed assumption that motor skill assessments that generate a composite score may better reflect MC (Bardid, Utesch, & Lenoir, 2019; Till Utesch et al., 2016), though applying a total score assumes that the MC test is a unidimensional construct reflecting Brace's original GMA hypothesis. Our findings with this sample of Iranians support the GMA hypothesis, though it is important to highlight that we excluded participants with self-reported orthopedic injury.

The TMC was designed to generate a composite score to reflect general MC, and it has the advantage that it can be administered across the lifespan to explore the MC construct and monitor its changes over time (Sigmundsson et al., 2016). But the basis for using the TMC with two dimensions relied on the assumption of the unidimensionality of MC, rather than on any empirical evidence of this unidimensionality.  Our main results demonstrate that the psychometric properties of the TMC were well adjusted to assess MC in Iranians aged 5-85 years. To test the construct validity of the TMC in this population, we calculated a series of CFAs with the four TMC tasks for three different age groups (i.e., child, adolescent, and adults) and the whole sample. We were able to confirm a unidimensional construct of MC in the TMC in each age group and in the total sample, and all items appeared to be measuring aspects of this same MC construct. The unidimensional model confirms that the items of the TMC can be used to compute a valid composite score reflecting individuals' MC in all age groups. The composite reliability values were also adequate for the one factor model of MC in three CFAs models and for the whole sample. The composite reliability values were >.60 which confirmed the TMC test battery has acceptable internal consistency (Hair et al., 2009), indicating the TMC is a reliable measure of MC across the lifespan in a population culturally and geographically different from the original Norwegian sample in which the TMC was first developed.

The GMA construct has been examined by others who also reported a unidimensional construct of children's MC tests including on the German Motor Proficiency Test for 4-6 year olds (MOT 4-6) (Till Utesch et al., 2016), the Bruininks-Oseretsky Test of Motor Proficiency 2nd Edition Short Form (Bardid et al., 2019) and the Test of Gross Motor Development-3 short version(TGMD-3 SF) (Duncan et al., 2022). The strength of this study was to determine a unidimensional construct of the TMC across the entire lifespan rather than only for children and adolescents. The unidimensional concept underpinning the TMC tests of dynamic balance and manual dexterity skills that are needed for activities of daily living for all age groups may provide a better measure of MC in adults than the motor skills used in many children's MC tests.

Our second aim in this study was to use a machine learning network analysis approach to investigate the associations between several biological variables (age, sex, and BMI) and the TMC test items. The association between these factors and MC have been previously determined in children (L. Barnett et al., 2016; Lubans et al., 2010), but they have not been examined in adults. The network analysis highlighted that age had a strong positive association with the Walking/Running in slopes item and was negatively associated with the Building Bricks and Heel-to-Toe Walking items. The ageing process often involves declines in the memory, perception, cognition, and progressive slowness with impaired motor ability. Prior investigators have suggested that ageing may have varying effects on different motor tasks; and ,while older people can perform some complex motor tasks automatically, they seem to require more brain activity to perform them at the same level as younger people (Wu & Hallett, 2005). This may explain the ageing effect on more complex TMC tasks (i.e., Building Bricks and Heel-to-Toe Walking). The associations between sex and the TMC test items were significant and indicated that males' test performance was faster than females' test performance on all tasks. While this is consistent with other evidence of childrens' and adolescents'sex differences on MC (Bolger et al., 2021), it is unclear whether the sex difference is maintained across the life span, as only one study has suggested that the difference is maintained (Rudisill & Toole, 1993). Cultural, climate, and geographical differences in Iran may contribute to adult sex differences in MC;  approximately one third of Iranian adults are insufficiently physically active, and the prevalence is higher in women (43%) than men (24%) (World Health Organization, 2015). An increase in the participants' BMIs was positively associated with age and with the Walking/Running in Slopes item on the TMC; and it was negatively associated with the remaining test items. This is consistent with other evidence of declines in functional and motor abilities with BMI increases, especially among children (Clark, Barnes, Holton, Summers, & Stratton, 2016) and adults (Wearing, Hennig, Byrne, Steele, & Hills, 2006) who are overweight and obese.

Little has been determined regarding population-level adult MC characteristics, especially in elderly populations. A Norwegian study measuring MC with the TMC in a sample of participants aged 7-79 years (n = 338) found that MC increased from childhood (age 7–9 years) to young adulthood (age 19–25 years) and then decreased from young adulthood (age 19–25 years) to old age (age 66–80 years) (Leversen, Haga, & Sigmundsson, 2012). The authors concluded that age related changes may be due to structural changes in the developing and aging brain. Others have shown that, during early childhood, development is associated with increased performance (e.g., decreased reaction times, increased processing speed and intelligence) (Fry & Hale, 2000) and, during adulthood, there is a linear decrease in performance on speed tasks (Verhaeghen, Steitz, Sliwinski, & Cerella, 2003).

Our findings are consistent with the results of prior studies showing associations between age and MC in children and adolescents (Barnett et al., 2016; Lester et al., 2017). The association between sex and MC remains unclear. Our network analysis showed that males achieved significantly better speed values than females, consistent with some prior research (Herrmann et al., 2015; Vedul-Kjels et al., 2013) while others have found no significant sex differences (Duncan et al., 2013; Juakkola et al., 2016).

Information on MC in different socio-cultural regions, such as the Middle East, is limited and has been identified as a research gap in understanding how socio-cultural and geographic contexts may influence MC (Lopes et al., 2021). To date, one study used the TMC to compare MC between children from northern Europe (Norway) and southern Europe (Greece and Italy) (Haga et al., 2018). Haga et al. (2018) showed that there were cross-cultural differences in MC between children living in northern versus southern Europe; Norwegian children performed better on all TMC tasks compared with Greek and Italian children. These differences also suggested there cross-cultural differences between northern and southern Europe that influence children’s MC. In Iran, research on MC is just emerging; there is a need to determine the psychometric properties of MC tests to measure and monitor MC and to allow cross-cultural comparisons. Iran is culturally and geographically different from other countries and regions; it is the fifth largest country in Asia (population ~ 85 million) with approximately 7% of its population aged >65 years (Statista, 2021). Our psychometric evaluation of the TMC among Iranians provides Iranian researchers with a MC test that can be used confidently across a wide age range.

### *Limitations and Future Directions*

Among limitations to this study, we only examined the associations of several biological variables (i.e., age, sex, and BMI) with the TMC items in our network analysis. We did not address the influence of other factors that have been associated with MC in children (e.g., physical activity, physical fitness, social economic status, and perceived MC), and they should be examined in future studies that include adults. We also did not examine measurement invariance of the one-factor structure of the TMC. Assessment of measurement invariance evaluation is needed to know whether the same underlying construct is being measured across groups or across time (Meredith, 1993). Future researchers should test TMC measurement invariance for sex and across ages before making factor-level comparisons with relevant external variables (Little, 2013).

## Conclusion

The TMC exhibited factorial validity with a unidimensional structure in a sample of Iranians aged 5-85 years, indicating that one latent trait underlies the TMC. This provides support for the general motor ability hypothesis. Our findings also show that the TMC can be used with confidence to measure MC in a culturally different population from the original Norwegian sample. Our CFA approach provided support for the theoretical definition of MC, which can be expanded to older age groups. Based on the acceptable composite reliability value, the TMC can be useful to provide an overall picture of the MC construct across the lifespan. The use of machine learning approach via network analysis in the present study allowed us to begin to better understand the interactions between variables as a complex system. Furthermore, the emerged network emphasized two TMC items, Placing Bricks and Building Bricks as the most critical centrality skills in MC, reinforcing the importance of fine motor skills for participating in activities of daily living across the lifespan.

**Table 1.** Means (and Standard Deviations) for Participants' (N = 500) Age, TMC Raw Score Times (Seconds) for Four Subtests, and TMC Total Z by Age and Sex

| **Age Group** | **Sex** | **n** | **Age** *M* (*SD*) | **PB** *M* (*SD*) | **BB** *M* (*SD*) | **HTW** *M* (*SD*) | **W/R** *M* (*SD*) | **Total TMC Z-scores** *M* (*SD*) |
|---|---|---|---|---|---|---|---|---|
| 5-9 years | F | 47 | 7.5 (1.3) | 32.8 (7.6) | 19.7 (7.2) | 16.4 (5.8) | 5.4 (1.2) | 2.3 (3.30) |
| | M | 53 | 7.6 (1.5) | 35.9 (7.9) | 20.8 (7.0) | 16.1 (5.1) | 6.2 (1.2) | 3.5 (3.1) |
| | All | 100 | 7.6 (1.4) | ***34.4 (7.8)*** [a] | ***20.3 (7.0)*** [a] | ***16.3 (5.5)*** [a] | 5.8 (1.2) | 2.97 (3.28) |
| 10-18 years | F | 92 | 13.9 (2.7) | 25.1 (3.5) | 14.0 (2.7) | 11.6 (3.2) | 5.0 (0.9) | -1.39 (1.61) |
| | M | 42 | 11.9 (1.6) | 28.1 (5.4) | 15.5 (3.4) | 12.1 (4.1) | 5.7 (1.3) | -0.06 (2.81) |
| | All | 134 | 12.9 (2.2) | 26.6 (4.5) | 14.8 (3.1) | 11.6 (3.7) | ***5.4 (2.2)*** [b] | -0.97 (2.14) |
| 19-25 years | F | 62 | 23.4 (1.7) | 23.9 (2.4) | 12.9 (1.8) | 10.3 (2.3) | 5.6 (1.0) | -1.74 (1.44) |
| | M | 14 | 22.7 (1.9) | 23.6 (2.7) | 12.4 (1.3) | 9.1 (1.4) | 5.6 (0.9) | -2.18 (0.95) |
| | All | 76 | 23.1 (1.8) | ***23.8 (2.6)*** [b] | ***12.7 (1.6)*** [b] | ***9.7 (1.9)*** [b] | ***5.6 (1.0)*** [b] | -1.82 (1.37) |
| 26-35 years | F | 82 | 28.6 (2.3) | 25.0 (3.9) | 12.9 (2.8) | 10.7 (2.3) | 6.1 (1.0) | -1.13 (1.65) |
| | M | 17 | 27.8 (2.5) | 23.4 (2.3) | 12.4 (1.6) | 10.0 (2.0) | 5.4 (0.8) | -2.13 (1.21) |

| Age Group | Sex | n | Age<br>*M* (*SD*) | PB<br>*M* (*SD*) | BB<br>*M* (*SD*) | HTW<br>*M* (*SD*) | W/R<br>*M* (*SD*) | Total TMC Z-scores<br>*M* (*SD*) |
|---|---|---|---|---|---|---|---|---|
| | All | 99 | 27.9 (2.4) | 24.2 (2.7) | ***12.7 (2.2)*** [b] | ***10.4 (2.2)*** [b] | 5.8 (0.9) | -1.30 (1.63) |
| 36-45 years | F | 20 | 39.3 (2.6) | 25.6 (2.4) | 14.3 (3.1) | 10.7 (2.3) | 6.3 (1.3) | -0.57 (1.59) |
| | M | 11 | 40.1 (4.1) | 25.9 (2.4) | 13.7 (2.9) | 10.7 (2.5) | 5.8 (0.8) | -1.04 (1.68) |
| | All | 31 | 39.7 (3.4) | ***25.8 (2.4)*** [b] | ***14.0 (3.0)*** [b] | ***10.7 (2.4)*** [b] | 6.05 (1.1) | -0.73 (1.61) |
| 46-55 years | F | 6 | 49.5 (1.6) | 29.9 (3.4) | 15.3 (3.0) | 11.7 (2.5) | 7.1 (1.5) | 1.09 (2.01) |
| | M | 14 | 50.7 (3.3) | 28.1 (3.1) | 14.3 (1.3) | 11.1 (0.8) | 5.8 (1.0) | -0.47 (1.30) |
| | All | 20 | 50.1 (2.5) | 29 (3.3) | 14.8 (2.2) | 11.4 (1.7) | 6.5 (1.3) | -0.0004 (1.66) |
| 56-65 years | F | 6 | 61.5 (4.5) | 28.4 (3.8) | 15.3 (3.6) | 12.1 (2.4) | 7.1 (1.4) | 1.06 (2.5) |
| | M | 16 | 62.0 (3.9) | 32.1 (10.6) | 17.1 (7.8) | 12.2 (1.8) | 7.6 (1.4) | 2.29 (3.96) |
| | All | 22 | 61.8 (4.2) | ***30.3 (7.2)*** [a] | ***16.2 (5.7)*** [a] | 12.2 (2.1) | ***7.4 (1.4)*** [a] | 1.95 (3.6) |
| 66-85 years | F | 3 | 81.7 (3.1) | 36.0 (8.3) | 18.7 (1.2) | 14.7 (0.5) | 9.4 (0.9) | 5.17 (0.56) |
| | M | 15 | 73.1 (6.7) | 39.2 (8.1) | 17.8 (3.0) | 13.8 (1.4) | 8.2 (1.1) | 4.31 (1.94) |
| | All | 18 | 77.4 (4.9) | ***37.6 (8.2)*** [a] | ***18.3 (2.1)*** [a] | ***14.3 (1.0)*** [a] | ***9.0 (1.0)*** [a] | 4.46 (1.90) |
| Total sample | F | 318 | 22.4 (12.8) | 26.4 (5.2) | 14.5 (4.3) | 11.8 (3.8) | 5.6 (1.2) | -0.64 (2.43) |

| Age Group | Sex | n | Age *M* (*SD*) | PB *M* (*SD*) | BB *M* (*SD*) | HTW *M* (*SD*) | W/R *M* (*SD*) | Total TMC Z-scores *M* (*SD*) |
|---|---|---|---|---|---|---|---|---|
| | M | 182 | 27.1 (22.6) | 30.7 (8.2) | 16.6 (5.7) | 12.8 (4.3) | 6.2 (1.4) | 1.12 (3.48) |
| | All | 500 | 24.8 (17.7) | 28.6 (6.7) | 15.6 (5.1) | 12.3 (4.1) | 5.9 (1.3) | 0.00001 (2.98) |

*Note:* F = female, M = male; a = significantly slower than the mean; b = significantly faster than the mean; PB = Placing Bricks; BB = Building Bricks; HTW = Heel-to-Toe Walking; W/R = Walking/Running on Slopes.

**Table 2.** Confirmatory Factor Analysis for Indexes of One-Factor Model of TMC by Age Group

| **Age Group** | **$\chi^2$ (df)** | ***p*-value** | **CFI** | **TLI** | **RMSEA** | **90%CI RMSEA** |
|---|---|---|---|---|---|---|
| **5-10 years** | 2.55 (2) | .280 | .996 | .987 | .04 | .00, .06 |
| **11-18 years** | 11.4 (2) | **.003** | .958 | .901 | .08 | .08, .11 |
| **19-85 years** | 21.6 (2) | **<.001** | .971 | .912 | .08 | .07, .10 |
| **Whole sample** | 517.706 (6) | .202 | .998 | .993 | .03 | .02, .04 |

*Note:* TMC= Test of Motor Competence; $\chi^2$ = chi-square statistic; CFI= comparative fit index; df= degrees of freedom; TLI= Tucker Lewis; RMSEA= mean square approximation error; bold *p* values are statistically significant

**Table 3.** Standardized Factor Loadings, $R^2$ and Composite Reliability for the One-Factor model of TMC Test Items by Age Group.

| TMC Test Item | Factor Loading | $R^2$ | Composite Reliability |
|---|---|---|---|
| **Age Group (5-10 years)** | | | |
| Placing Bricks | .94* | .89 | |
| Building Bricks | .73* | .53 | .74 |
| Heel to toe walking | .46* | .21 | |
| Walking/running in slopes | .40* | .16 | |
| **Age Group (11-18 years)** | | | |
| Placing Bricks | .58* | .33 | |
| Building Bricks | .69* | .47 | 0.73 |
| Heel to toe walking | .80* | .64 | |
| Walking/running in slopes | .47* | .22 | |
| **Age-group (18-85 years)** | | | |
| Placing Bricks | .47* | .22 | |
| Building Bricks | .70* | .49 | .60 |
| Heel to toe walking | .62* | .38 | |
| Walking/running in slopes | .30* | .09 | |
| **Whole sample (5-85 years)** | | | |
| Placing Bricks | .94* | .89 | |
| Building Bricks | .73* | .53 | .74 |
| Heel to toe walking | .43* | .21 | |
| Walking/running in slopes | .40* | .16 | |

*Note:* *p<.001

**Table 4.** Network Analysis Weights Matrix.

| **Variables** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|
| 1. Age | 0 | | | | | | |
| 2. Sex | .15 | 0 | | | | | |
| 3. Placing Bricks | .22 | .37 | 0 | | | | |
| 4. Building Bricks | -.14 | .25 | .74 | 0 | | | |
| 5. Heel-to-toe walking | -.19 | .15 | .44 | .35 | 0 | | |
| 6. Walking/running in slopes | .44 | .26 | .41 | 0,25 | .22 | 0 | |
| 7. BMI | .58 | -.04 | -.18 | -.26 | -.22 | .23 | 0 |

*Note:* BMI=body mass index; Red shading represents negative relationships and blue shading represents positive relationships. The magnitude of the color is related to the intensity of the relationship.

**Table 5.** Centrality Measures for Four TMI Subtests and Participants' Biological Variables.

| **Variable** | **Betweenness** | **Closeness** | **Strength** |
|---|---|---|---|
| Placing Bricks | **.953** | **1.513** | **1.459** |
| Building Bricks | **.953** | **.682** | **.983** |
| Heel-to-toe walking | -1.270 | -.142 | -.342 |
| Walking/running in slopes | .941 | .659 | .393 |
| Age | -.159 | -.478 | -.507 |
| Sex | -1.270 | -1.300 | -1.442 |
| BMI | -.159 | -.935 | -.544 |

*Note:* BMI=body mass index; Values in bold are the highest values for each centrality measure.

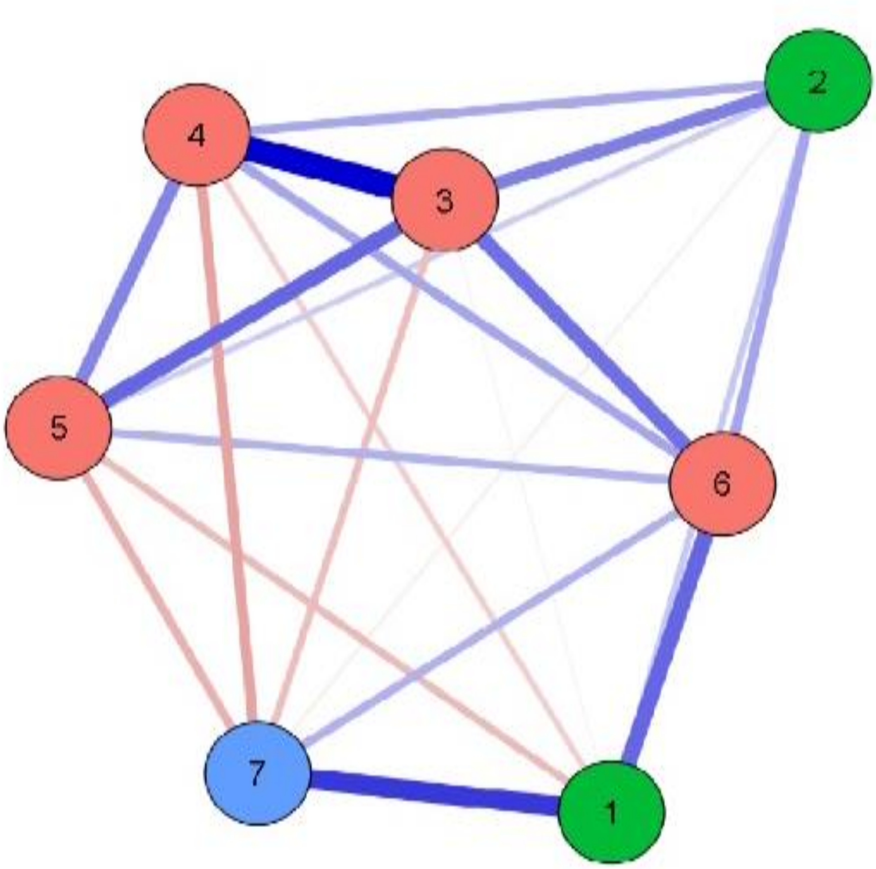


**Figure 1**. Network Association Between Four TMC items and Participants' Biological Variables of Sex, Age, and BMI;

*Note:* 1 = Age; 2 = Sex; 3 = Placing Bricks; 4 = Building Bricks; 5 = Heel-to-toe walking; 6 = Walking/ running in slops; 7 = BMI. Positive associations are expressed by the blue color and negative associations by the red color. Thickness of the path indicates the weight of the ratio.

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