
Journal of Sports Sciences

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rjsp20

# Model invariance of the Motor Competence Assessment (MCA) from early childhood to young adulthood

**Luis P. Rodrigues, Rita Cordovil, Carlos Luz & Vitor P. Lopes**

**To cite this article:** Luis P. Rodrigues, Rita Cordovil, Carlos Luz & Vitor P. Lopes (2021): Model invariance of the Motor Competence Assessment (MCA) from early childhood to young adulthood, Journal of Sports Sciences, DOI: 10.1080/02640414.2021.1932290

**To link to this article:** https://doi.org/10.1080/02640414.2021.1932290

JOURNAL OF SPORTS SCIENCES
https://doi.org/10.1080/02640414.2021.1932290



PHYSICAL ACTIVITY, HEALTH AND EXERCISE

# Model invariance of the Motor Competence Assessment (MCA) from early childhood to young adulthood

Luis P. Rodrigues [a,b], Rita Cordovil [c,d], Carlos Luz [e,f] and Vitor P. Lopes [b,g]

[a]Instituto Politécnico de Viana do Castelo, Escola Superior Desporto e Lazer de Melgaço, Viana do Castelo, Portugal; [b]Research Center in Sports Sciences, Health and Human Development (CIDESD), Vila Real, Portugal; [c]Faculdade de Motricidade Humana, Universidade de Lisboa, Lisboa, Portugal; [d]Interdisciplinary Center for the Study of Human Performance (CIPER), Lisboa, Portugal; [e]Escola Superior de Educação de Lisboa, Instituto Politécnico de Lisboa, Lisboa, Portugal; [f]Centro Interdisciplinar de Estudos Educacionais, Lisboa, Portugal; [g]Escola Superior de Educação, Instituto Politécnico de Bragança, Bragança, Portugal

**ABSTRACT**

The Motor Competence Assessment (MCA) is an innovative instrument to assess motor competence along the lifespan. The MCA model and normative values were recently established from the age of 3-to-23 years old. The purpose of this study was to validate MCA from early childhood to young adulthood.

One thousand participants representing four age groups (3–6, 7–10, 11–16, 17–22 years) with 250 participants each, were assessed. Invariance of the MCA model along the age groups – configural, metric and structural – was tested using multigroup CFA.

The MCA model showed to fit well all age groups. The multigroup unconstrained model showed a very good fit (NFI=0.99; TLI=0.99; CFI=0.99; RMSEA=0.03). A formal test for the invariance of loading coefficients returned a non-satisfactory goodness-of-fit adjustment and a significant difference with the unconstrained model ($\Delta\chi^2$ = 539.57; $\Delta$df = 18; *p*= .00). The structural invariance testing did not show formal invariance between factor correlations ($\Delta\chi^2$ = 73.04; $\Delta$df = 9; *p*= .00) but the fit of the model was acceptable (above 0.96 and a RMSEA of 0.05), indicating that correlation values inter factors are stable.

This study adds information for the validation of the MCA as a useful instrument for assessing motor competence throughout the life cycle.

**ARTICLE HISTORY**
Accepted 17 May 2021

**KEYWORDS**
Child development; motor development; motor assessment; motor performance; lifespan

## Introduction

Motor competence is a global term that relates to the development and performance of human movement, and it has been defined in the literature as a person's ability to be proficient in a broad range of locomotor, stability and manipulative gross motor skills (Utesch & Bardid, 2019). Furthermore, it is expected to facilitate the learning of new skills and the motor proficiency on novel motor tasks throughout the lifespan.

Motor competence research had a huge increase in the last decade, particularly after the publication of the Stodden and collaborators' model in 2008 (Stodden et al., 2008). In this highly cited paper, the proposed model was a re-visitation of the seminal concepts of motor development originated in the 1970s and 1980s by several authors (Gallahue, 1982; Payne & Isaacs, 1987; Roberton & Halverson, 1984; Wickstrom, 1970), extending the scope to a lifelong perspective.

Although hundreds of research articles were written addressing motor competence, no instrument existed to specifically evaluate lifelong motor competence until the Motor Competence Assessment (MCA) was developed (Luz et al., 2016). All previous instruments used in the literature as a MC proxi (e.g., KTK, TGMD, M-ABC, etc.) specifically targeted gross motor coordination, fundamental motor skills (FMS) development or motor development; fail to entail the all range of motor skills (stability, locomotor and manipulative); only cover a limited age span usually early childhood, or childhood; were mostly directed to diagnose motor impairment; or present a ceiling effect that difficult the discrimination of the best, more competent performers (Luz et al., 2017, 2016).

The MCA (Luz et al., 2016; Rodrigues et al., 2019) is an innovative instrument to assess motor competence along the lifespan. In the MCA original publication, its construct validity was established by a model with three correlated components: locomotor, stability, and manipulative, each of them assessed by two different objectively measured tests. Other specifications of the MCA were that all motor tests are quantitative (product-oriented), without a marked developmental (age) ceiling effect, and of feasible execution to diminish observation errors.

In 2019 the normative values for the MCA six tests were published (Rodrigues et al., 2019). It was the first time that the same test battery was used to assess the three components of motor competence from childhood (3 years of age) to early adulthood (23 years of age), according to sex and age. These normative results showed the applicability and usefulness of the MCA tests along the first two decades of life, but the

**CONTACT** Luis P. Rodrigues lprodrigues@esdl.ipvc.pt Escola Superior Desporto E Lazer De Melgaço, Complexo Desportivo E De Lazer Comendador Rui Solheiro, Melgaço 4960-320, Portugal

All authors contributed equally for the study and manuscript writing.

Supplemental data for this article can be accessed online https://doi.org/10.1080/02640414.2021.1932290.

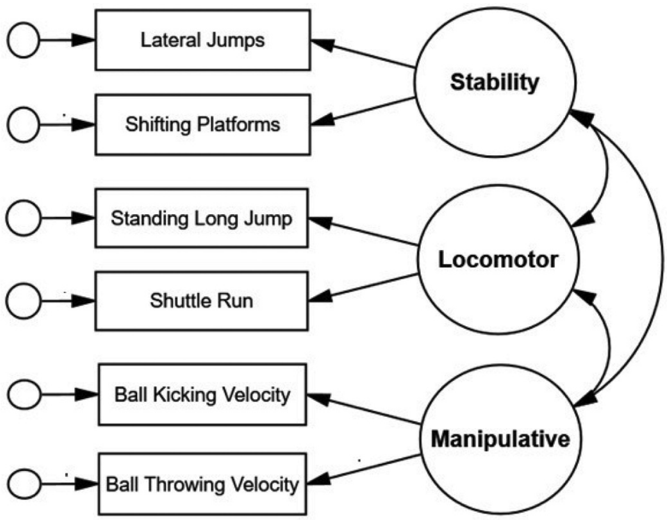


**Figure 1.** MCA configural model (Luz et al., 2016).

normative values for the MCA components (locomotor, stability and manipulative) and Total MCA still need to be built and validated. To do so that is the need to test for the validity of the proposed MCA configuration along different developmental stages. Being an instrument that uses product measures of motor skills, their developmental age-related sequences cannot be ignored. Stability, locomotor and manipulative motor skills develop through known periods of initial learning patterns, to elementary phases of motor practice, and finally to the achievement of a mature motor pattern that can be consolidated through exercise and practice to a specialized (sportive) motor skill. Throughout adulthood and later in life, motor skills proficiency is still susceptible to change (Gabbard, 2018; Goodway et al., 2019). These sequential phases are naturally linked to age and maturational demands, but also to the time spent on practicing the different skills (Malina et al., 2004). Because MCA intends to be a lifelong motor competence assessment, there is the need to understand if the proposed model construct (see Figure 1) stands for all age periods.

This is the purpose of this study, to evaluate the MCA hypothesized configural invariance between age groups from early childhood to young adulthood. Our expectation is that no major differences are to be found in the MCA main structure along these periods of life, although changes in performance and their relationship are naturally expected amongst tests and components.

## Materials and methods

### Participants

The database used in this study belongs to an ongoing project that aims to collect data on motor competence in Portugal, Europe. A convenience sample data was collected in three different Portuguese locations. Participants were students of all education levels, from preschool to university, with no motor or cognitive impairment. From an initial database of 2083 participants (1131 males) between 3 and 23 years of age, 250 participants were selected by a computer randomization program according to sex and age to represent each of the four age group subsamples (3–6, 7–10, 11–16, and more than 17 years of age), resulting on a total of 1 000 participants. No differences were found between the selected and non-selected participants on any of the MCA tests (all *ps*>.50)

The study was approved by the Scientific Council of the School of Sports and Leisure of the Polytechnic Institute of Viana do Castelo, and by the Ethics Committee of the Faculty of Human Kinetics of the University of Lisbon. School directors approved the study, adult participants and parents or tutors of underage children gave their informed consent, and children gave their verbal assent prior to data collection. All procedures were in accordance with the 1964 Helsinki Declaration and its later amendments.

### 2.2 Data collection

The MCA is composed of two tests for each MC component, namely stability: lateral jumps (LJ), shifting platforms (SP); locomotor: standing long jump (SLJ), 10 m shuttle run (SHR) and manipulative: ball kicking velocity (BKV), ball throwing velocity (BTV). All tests are quantitative (product-oriented) motor tests without a marked developmental (age) ceiling effect, and of feasible execution (for a full description, see Rodrigues et al., 2019). Reliability of the tests used has been described in the literatures as ranging from good to excellent (AAHPER, 1975; Fernandez-Santos et al., 2015; Iivonen et al., 2015; Rodrigues et al., 2005), and the intraclass correlation coeficient (ICC) values found in this sample were of 0.950, 0.987, 0.968, 0.987, 0.979 and 0.983, respectively for SP, JS, SHR, SLJ, BKV and BTV.

Before starting to test, all participants completed a 10 min general and standardized warm-up. Participants performed all the tests in small groups (about five children for each task). Examiners were trained for administering all tests, including a previous collection of a pilot study with 20 participants. The following requirements were used as standard: (a) a proficient demonstration of each test technique was provided along with a verbal explanation; (b) every participant experimented each task before the actual test administration; (c) the instructions emphasized that participants should try to perform the task at their maximum potential (e.g., "as fast as possible" for the stability tests and 4 × 10 shuttle run; "as far as possible" for the standing long jump; and "as hard as possible" for the manipulative tests); and (d) motivational feedback was given; however, no verbal feedback on skill performance was provided. At all time, at least one of the three first authors of this study personally supervised data collection. Evaluations were done in a school gymnasium at each of the three different locations.

### Statistical analyses

The sample of 1000 participants represented four age group subsamples (3–6, 7–10, 11–16 and 17–22 years) with 250 participants each. A post-hoc analysis to the sample size and power using the parameter's values found in the CFA suggests that an estimated power of 0.89 could be achieved using a sample size as small as 100, well below our number (Wolf et al., 2013).

Univariate and multivariate normality of distribution was tested for all samples' models. Skewness values higher than 3, and kurtosis or multivariate kurtosis higher than 10 were considered non-normal distributions, and in this case 2000 Bollen–Stine bootstrap samples were used for correction (Kline, 2004). Pearson bivariate correlation between tests for the four age groups was found. Correlation's strength was considered weak from values of 0.10 to 0.39; moderate from 0.40 to 0.69; and strong from 0.70 to 0.89 (Schober et al., 2018)

Initially, to each age-group sample the MCA model configuration (Luz et al., 2016) was imposed while leaving all parameters to vary freely. The absolute fit of the models (individual and multigroup analysis) was evaluated using the chi-square by degrees of freedom ratio (χ2/df), while relative fit was assessed using the normed fit index (NFI), the Tucker–Lewis index (TLI) and the comparative fit index (CFI). For these indices, values over 0.95 are deemed indicative of a good fit, and values over 0.98 of a very good fit (Byrne, 2006; Hu & Bentler, 1999). The standardized root mean square residual (SRMSR) was also used as an absolute measure of the model fit, and a cut-off value of 0.08 was considered as criteria (Hu & Bentler, 1999). The root mean square error of approximation (RMSEA) was used for evaluating how well the model implied reproduced the variance–covariance matrix of the data, keeping in mind that RMSEA values as low as 0.08 are deemed adequate and below 0.06 represent a good fit to the model (Hancock & Freeman, 2001; MacCallum et al., 1996).

Modification indices were inspected for all models and interpreted within the theoretical framework tested. Average variance extracted (AVE) was calculated for testing convergent validity of the factors for each age group model. Values above 0.5 are indicative of good convergent validity of the items into the factor (Hair et al., 2013). To further assess discriminant validity, we determined the Heterotrait–Monotrait ratio of correlations (HTMT) between factors and a cut-off value of <0.85 was used for indicating adequate discriminant validity (Henseler et al., 2015). Composite reliability or construct reliability of the four tested age models was assessed as a measure of internal consistency in scale items, and threshold values of 0.80 were adopted as a rule of thumb (Brunner & Süβ, 2005).

Invariance of the MCA model – configural, measurement and structural – was tested using multigroup CFA for the four age groups using maximum likelihood estimation. The multigroup confirmatory analysis involved three nested models: (1) configural invariance, to analyse if the number of factors and items in each factor of the proposed MCA model were acceptable for the all the age groups; (2) metric or measurement invariance, to analyse if the factorial loadings were similar between age groups; and (3) structural invariance, to analyse if the covariance between the three factors (correlation) were similar for age groups.

Configural invariance was tested by imposing the MCA-proposed model structure (Figure 1) with all parameters free (unconstrained model). Invariance of factor-item coefficients was tested imposing the equality across models for each loading (measurement model). Between-factors correlation invariance was tested by constraining all factor correlations to equality (structural covariances model) while leaving all other parameters to vary freely. Each of the two last models were compared with the multigroup unconstrained model (nested within), using the chi-square change and respective degrees of freedom. Complete invariance of the parameters tested was only concluded when non-significant differences were found between them. Pairwise parameter comparisons of the unconstrained parameters were used to detect significant differences between the tested parameters (loadings and correlations) of consecutive models.

All analyses were conducted using the IBM© SPSS© Amos 25.0 computer program.

## Results

Descriptive values for all tests and subscales of the MCA are presented in supplementary materials (Table 1). The Pearson correlation matrices between the six MCA tests for each age group are presented in Table 1.

All correlation values between test items for the different age groups were found to be statistically significant. Strength of the correlations varied from moderate (on 67% of the cases) to strong (33%) in the first age group (3–6 years). At the 7–10 years age group ranged from weak (53%) to moderate (47%). In the 11–16 years age group, we found mostly moderate (67%) and strong correlation values (27%). In the older group, the weak (47%) and moderate correlations were predominant (33%).

The goodness of fit resulting from the imposition of the configuration of the original MCA model (Figure 1) (Luz et al., 2016) on each of the four age groups and on the combined group (multi-group) are shown in Table 2.

The imposed MCA model showed to fit well all age groups, presenting reasonable up to very good fit indices. All loading coefficients and factor covariances (correlations) for all tested age group's model were statically significant ($p < .05$), showing to be usefully marking the respective latent factor. Furthermore, scrutiny of the modification indices did not show any suggestion for different paths of the loadings for

Table 1. Correlation matrix between the six MCA testing variables for the four age groups.

| Age group | | LJ | SP | SLJ | SHR | BK |
|---|---|---|---|---|---|---|
| 3–6 | SP | 0.78 | | | | |
| | SLJ | 0.74 | 0.78 | | | |
| | SHR | −0.65 | −0.71 | −0.75 | | |
| | BKV | 0.64 | 0.67 | 0.68 | −0.65 | |
| | BTV | 0.61 | 0.62 | 0.64 | −0.59 | 0.65 |
| | SP | 0.50 | | | | |
| 7–10 | SLJ | 0.40 | 0.39 | | | |
| | SHR | −0.58 | −0.37 | −0.54 | | |
| | BKV | 0.27 | 0.17 | 0.29 | −0.48 | |
| | BTV | 0.24 | 0.24 | 0.35 | −0.40 | 0.64 |
| | SP | 0.63 | | | | |
| 11–16 | SLJ | 0.57 | 0.62 | | | |
| | SHR | −0.57 | −0.59 | −0.81 | | |
| | BKV | 0.35 | 0.42 | 0.70 | −0.62 | |
| | BTV | 0.41 | 0.47 | 0.72 | −0.63 | 0.81 |
| | SP | 0.49 | | | | |
| 17–22 | SLJ | 0.38 | 0.37 | | | |
| | SHR | −0.43 | −0.34 | −0.69 | | |
| | BKV | 0.36 | 0.30 | 0.74 | −0.67 | |
| | BTV | 0.35 | 0.28 | 0.74 | −0.62 | 0.84 |

LJ, lateral jumps; SP, shifting platforms; SLJ, standing long jump; SHR, shuttle run; BKV, ball kicking velocity; BTV, ball throwing velocity.

Table 2. Goodness-of-fit results for the MCA unconstrained model tested for the four age groups and the multigroup analysis.

| Models | $\chi^2$ | df | $\chi^2$/df | NFI | TLI | CFI | SRMSR | RMSEA |
|---|---|---|---|---|---|---|---|---|
| 3–6 years | 3.51 | 6 | 0.585 | 0.99 | 1.00 | 1.00 | 0.009 | 0.000 |
| 7–10 years | 16.98 | 6 | 2.829 | 0.97 | 0.94 | 0.98 | 0.032 | 0.086 |
| 11–16 years | 8.43 | 6 | 1.405 | 0.99 | 0.99 | 1.00 | 0.017 | 0.040 |
| 17–23 years | 12.68 | 6 | 2.113 | 0.98 | 0.98 | 0.99 | 0.019 | 0.067 |
| Multigroup invariance analysis tested models | | | | | | | | |
| Configural | 41.59 | 24 | 1.733 | 0.988 | 0.987 | 0.995 | 0.009 | 0.027 |
| Metric | 581.15 | 42 | 13.837 | 0.831 | 0.772 | 0.840 | 0.190 | 0.114 |
| Structural | 114.63 | 33 | 3.474 | 0.967 | 0.956 | 0.976 | 0.085 | 0.050 |

any of the age groups. The multigroup unconstrained model showed a very good fit of the MCA model to the overall age groups tested.

When loading's values were constrained to equality between age groups for testing measurement weights invariance, goodness-of-fit results were low and the formal test comparison showed no formal invariance for the loading values throughout group ages ($\Delta\chi^2$ = 539.57; $\Delta$df = 18; $p<$ .001). Analysis of the invariance relative to the structural covariance between latent factors returned very acceptable goodness-of-fit indices, but the formal test did not hold for the invariance between the inter-factors correlation values for all age groups ($\Delta\chi^2$ = 73.04; $\Delta$df = 9; $p<$ .001).

Loadings factor-item, correlation and HTMT values between factors for the unconstrained model are presented in Table 3, with significant differences between each sequential model loading coefficients (e.g., each model parameters compared with next age group). Convergent validity was adequate for all models in general, with AVE showing values above the 0.5 indicated as rule of thumb (Hair et al., 2013), the exception being the stability factor (F1) at the age group of 17–22. HTMT between factors of the different models were indicative of good discriminant validity for the three older age groups, but of a low discriminant validity for the younger age group (3–-6 years). Composite reliability (also known as construct reliability) of the latent variables for all the four tested models was high, ranging from 0.76 to 0.99, showing that the shared variance among the observed variables of each latent construct was consistently adequate throughout the models (Brunner & Süβ, 2005).

## Discussion

This work aims to understand if the MCA model proposed by Luz et al. (2016) can be used to assess motor competence throughout the different developmental periods of motor skill acquisition and consolidation. To test this hypothesis, we imposed the structure of the model (Figure 1) on the four different age groups and assessed its validity. The MCA model is composed of three components or sub-scales corresponding to the theoretical and research-driven FMS categories: stability, locomotor and manipulative. These three sub-scales are represented by the correlated latent factors in the model, each one defined by the results of two relevant tests. The normative performance of these six tests that compose the MCA battery has already been established from the age of 3 to 22 years of age (Rodrigues et al., 2019). The need now was to verify if the construct of motor competence, as measured by the MCA, is stable along the growing ages or does it change? And how can the sub-scales and the total MCA evaluation and classification be built considering to this information?

### *Tests correlation matrix*

The results of the correlations showed a pattern in the strength of the associations between the MC categories and the age groups. Thus, the younger age group (3–5 years old) displayed the highest correlation values between the stability tests ($r$ = 0.78), the group from 11 to 16 years old had the highest value between tests in the locomotor category ($r$ = −0.81) and the older age groups (17–22 years old) presented the highest value among the manipulative category tests ($r$ = 0.84). Finally, the age group from 7 to 10 years showed, generally, the lowest

Table 3. Factor-item loadings, explained variance, correlation between factors, average variance extracted and composite reliability for the unconstrained model imposed in the four age groups.

| | 3–6 | | | | 7–10 | | | | 11–16 | | | | 17–22 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **F1** | **F2** | **F3** | $R^2$ | **F1** | **F2** | **F3** | $R^2$ | **F1** | **F2** | **F3** | $R^2$ | **F1** | **F2** | **F3** | $R^2$ |
| LJ | .86 | - | - | **.74** | .85 | - | - | **.72** | .77 | - | - | **.59** | .73 | - | - | **.54** |
| SP | *.90* | - | - | **.82** | *.59* | - | - | **.35** | *.82* | - | - | **.67** | .66 | - | - | **.44** |
| SLJ | - | *.89* | - | **.80** | - | *.63* | - | **.39** | - | .94 | - | **.89** | - | .88 | - | **.77** |
| SHR | - | *−.82* | - | **.67** | - | −.86 | - | **.73** | - | *−.86* | - | **.74** | - | −.79 | - | **.62** |
| BKV | - | - | .82 | **.68** | - | - | *.85* | **.71** | - | - | *.89* | **.79** | - | - | .93 | **.86** |
| BTV | - | - | .78 | **.61** | - | - | *.76* | **.58** | - | - | *.91* | **.82** | - | - | .91 | **.82** |
| AVE | .77 | .73 | .64 | | .54 | .57 | .65 | | .63 | .81 | .81 | | .48 | .70 | .85 | |
| CR | .93 | .91 | .86 | | .79 | .81 | .87 | | .86 | .94 | .94 | | .76 | .99 | 85 | |
| HTMT | | | | | | | | | | | | | | | | |
| F1–F2 | | .94 | | | | .84 | | | | .82 | | | | .65 | | |
| F1–F3 | | .89 | | | | .41 | | | | .58 | | | | .50 | | |
| F2–F3 | | .92 | | | | .65 | | | | .82 | | | | .91 | | |
| Factor correlations | | | | | | | | | | | | | | | | |
| F1–F2 | | *.94* | | | | .79 | | | | *.81* | | | | .64 | | |
| F1–F3 | | *.86* | | | | *.38* | | | | *.59* | | | | .51 | | |
| F2–F3 | | *.91* | | | | *.64* | | | | .83 | | | | .91 | | |

F1, stability; F2, locomotor; F3, manipulative;

LJ, lateral jumps; SP, shifting platforms; SLJ, standing long jump; SHR, shuttle run; BKV, ball kicking velocity; BTV, ball throwing velocity; F1, stability; F2, locomotor; F3, manipulative;

CR, composite reliability; HTMT, Heterotrait–Monotrait ratio of correlations.

Loading coefficient significantly different from the next age group is *Italicized and underscored.*

correlation values for all MC categories. These results highlight that the development of motor competence is multidetermined and dynamic (Thelen, 1986). Stability skills are of great importance in children's early development and the form the basis for the development of locomotor and manipulative skills (Adolph & Hoch, 2019; Rudd et al., 2015). During the development of motor competence, the different contributing components do not seem to mature in a synchronous fashion, their rates of change seem to vary sometime mildly and sometimes more abruptly and that has implications in the relative contribution of each factor for the overall children's or adolescent's level of motor development (Malina et al., 2004).

### *Unconstrained model (configural invariance)*

The multigroup unconstrained model showed a very good fit of the MCA model to the overall age groups tested, with all fit indices denoting appropriate high values (NFI = 0.99; TLI = 0.99; CFI = = 0.99; SRMSR = 0.009; RMSEA = 0.027). Overall this allows to conclude that the previously proposed model (Luz et al., 2016) (Figure 1) proved adequate to represent motor competence throughout the tested ages, even if the specific adjustment for the different age groups were not exactly the same, as discussed below.

Given the developmental sequences of the FMS, we expect children to learn and develop their FMS from the initial attempts up to a mature performance during childhood with special emphasis on the 3–6 years of age period (Goodway et al., 2019). During this period, children motor control and proficiency still lingers to maturation, although less and less each year. Because of that, homogeneity between children motor performance is more evident than later, probably explaining why the better representation (loading coefficients and $R^2$ values) of the tests into the latent factors, along with the higher goodness-of-fit indices and correlation values between sub-scales (factors) was found in this age group.

The 7–10 years age group showed a less good adjustment result for the MCA model, although still acceptable. Trusting on the data, motor competence at this time seems to be less identified by this MCA model, and proficiency in each subscale less correlated to the others. Particularly low, relative to all other ages, was the correlation between stability and manipulative categories. From the 7−−10 years of age, children are supposed to consolidate their motor skill performance and to use them in combined and more refined ways, up to the initial forms of specialized skills. These acquisitions depend mainly on practice time and opportunities (e.g., free play, peer support, sports involvement and PE; Gabbard, 2018). Consequently, movement and performance grow in diversity, with children showing different patterns of motor skills development both in quantity and quality. This can explain the lower adherence to the MCA model at these ages. It also denotes the need for a more structured PE practice in primary schools to offer challenging movement opportunities for all children.

FMS are the building blocks for motor competence development in childhood and adolescence and were described as to be fully developed and ready to support more complex and combined movements at the age of 6 years old (Gallahue & Ozmun, 1995). Nevertheless, at the present time several studies have shown that mastery on FMS is delayed up to the age of the end of primary school, and not always achieved by every child (Behan et al., 2019; Hardy et al., 2013). In Ireland, children tested on their FMS showed that at 7 years of age only 27% achieved mastery or near mastery on stability motor skills; 41% on locomotor motor skills and 32% in manipulative motor skills. At the age of 10, these percentages were up to 64%, 54% and 52%, showing that only about half of the children were able to master their basic movement patterns. Similar results were found in England where only 25% of fourth graders were able to show mastery on all four tested FMS (run, jump, throw and catch), and less than one-fifth of children between the ages of 6–9 years old mastered these four key motor skills (Duncan et al., 2019). These results are showing that motor skill's proficiency that was supposed to be matched at the age of 6 years is nowadays postponed several years down the developmental path and sometimes it never happens. Consequences are that during primary school years children still present non-mature movement patterns, resulting in low-performance constancy and high variability between and within children. This inconsistency results on a less structured collective motor competence, with large individual heterogeneity on the movement performance of motor skills and its categories.

For the 11–16 years of age, we found very good adjustment to the configuration of the proposed MCA model with all goodness-of-fit indices above 0.99 and the RMSEA below 0.5. Factor loading coefficients are high (all above 0.77) and making use of a significant amount of the items' variance into the latent factors (MCA subscales). Correlations between latent factors are higher than in the previous age period and range from moderate (stability – manipulative) to strong (the other two). At this age period, motor competence is expected to be more heterogeneous among adolescents not only because sex-related differences start to become more evident favouring boys, but also because adolescents start to be more different as a result of the previous motor experience and learning (Gabbard, 2018).

In a period when motivation for different areas of human activity is crucial in adolescent's choices and experiences, and the participation in organized sports is growing, motor competence levels are expected to become more stable (see age-related results of motor skill acquisition; Gabbard, 2018; Rodrigues et al., 2019). This can explain the better results of the model testing at an age where some adolescents show a successful motor skill acquisition and are ready for a specialized sports initiation, while some others were not able to consolidate their motor experiences and will show low efficacy on solving motor challenges. But all of them are expected to be more homogeneous throughout the full spectrum of motor competence, which results in a better adherence to the MCA model.

On the next age period (17–22), the MCA model seems to keep representing well the motor competence structural relationships. Goodness-of-fit indices are high (all above 0.98) and the RMSEA is worse than for the previous age group but still very acceptable. These small differences can be probably explained by the life changes that youngsters experience after adolescence. Changing to university (most of the participants at this age period where young university students) probably results in changes in lifestyles that can impact motor competence inner relationships (Winpenny et al., 2020). Also, youngsters that thrive in sports are probably specializing more in specific components of motor competence, altering the structure of its component's relationship. In fact, the correlation values between the subscales show the lowest value for two of the three combinations at this age group. Overall, AVE for each factor (see AVE in Table 2) showed convergent validity of the factors for all age models, meaning that each factor represents well the items behaviour, and composite reliability is also high for all latent variables, denoting that the total amount of true score variance relative to the total scale's score variance was good.

### *Invariance of loading coefficients and subscales (metric invariance)*

The formal test for the invariance of loading coefficients for overall age groups returned a non-satisfactory goodness-of-fit adjustment (see Table 2) and a significant difference with the unconstrained model ($\Delta\chi^2 = 539.57$; $\Delta df = 18$; $p = .00$), meaning that the degree to which test contribute towards the latent construct (e.g., stability) was not the same from age to age. Looking for similitudes between each contiguous age group loading coefficients (see Table 3), we can see half of the coefficients remained invariant from 3–6 to 7–10 age group (LJ, KBV, TBV); two from 7–10 to 11–16 (LJ, SHR) and two from 11–16 to 17–22 age group (LJ, SLJ).

Overall, the within-factors (subscales) configuration of the loading coefficients remained stable with both item-factor coefficients showing shared similar representation on the factor, except for the 7–10 age group in the stability and locomotor factors. The contribution of the items for each factor generally increased for the manipulative factor, decreased for the stability factor and remained stable for the locomotor factor (see AVE in Table 2).

These fluctuations on the relative relevance of the items (tests) for marking the individual MCA factors were expected given the known motor development characteristics associated with growing up (Gabbard, 2018; Goodway et al., 2019). The results can be related to the ontogeny of movement behaviour and the complexification of movement behaviour (Adolph & Hoch, 2019). Stability movements are very important in the first phase of movement acquisition, locomotor skills are next in acquisition order and gross manipulative motor skills are the last ones to develop (Gallahue & Ozmun, 1995). But the fact to retain is that even if the relational nature of the items in the model changed, their relevance to the common configuration remained high, showing that the model factor structure can represent well these developmental motor competence changes.

### *Invariance of factor covariances (structural invariance)*

For testing the invariance of covariances between the three factors, only the correlation parameters in the model were constrained to equality. The test did not show formal invariance between inter-factor correlation measures ($\Delta\chi^2 = 73.04$; $\Delta df = 9$; $p = .00$) but the fit of the model was acceptable (all goodness-of-fit indices above 0.96, SRMSR of 0.085 and an RMSEA of 0.05), indicating that correlation values between factors should be relatively stable.

Looking for the inter-factor correlation values along the age groups, we see that they tend to decrease along the age groups, showing that the three proposed factors or components of motor competence are more orthogonal (independent) as growing old. This makes sense from a developmental and learning perspective since with age comes a more specialized motor competence.

Stability latent factor showed to be the more independent component of MCA. The correlation values with the manipulative factor were the lowest for all four age groups, and mostly moderate in nature. At the first age group, the correlation between stability and locomotor is the highest, resulting on a worst discriminant validity of the factors, probably because of the ontogenetic described mechanism of building the locomotor skills supported by the body stability, but correlation values with locomotor latent factor decreases to be the second lowest in the last two age groups. The manipulative and locomotor components of the MCA model seem to be strongly associated throughout the age groups, and locomotor latent factor is the one sharing more variance with the two others for all age-tested models. Most sports practised by children and adolescents use a combination between locomotor and manipulative skills, what could explain this increasing association along the age groups (Barnett et al., 2008).

Overall, the correlation pattern between latent factors was similar across ages, showing that although varying on their degree of inter-dependency, we should expect that each factor contribution to motor competence is not unique and that shared performance is to be expected as postulated in the MCA structural model.

Research testing for the invariance across age of motor assessment instruments (e.g., motor skill, motor competence, gross motor coordination) are very scarce in the literature. Just very recently the construct validity of the bi-factor model for the new version of the Test of Gross Motor Development 3 (TGMD-3) was tested using a large sample of Italian children. In this study, three age groups (3–7, 8–9 and 10–11 years) were used in a multigroup confirmatory factor analysis, similar to our method (Magistro et al., 2020). The authors found TGMD-3 to be configural, metric and structural invariant across age groups, unlike our findings for MCA, but the age groups and age span were different from the present study. Furthermore, the TGMD-3 is a qualitative instrument that uses only two factors (locomotor and object control), and the authors pointed out that the TGMD-3 showed a low discriminative power between performers with high or very high scores (Magistro et al., 2020), probably because TGMD was originally developed for identifying developmental delays during childhood (Ulrich & Sanford, 1985), and several of the tests used have a ceiling effect with age (Luz et al., 2017). In the conclusions, the study authors emphasized the overlapping effect of the ball skills tasks and propose reducing the number of single skills or substitute some of them with more difficult tasks. These considerations and concerns were really in the basis of the MCA development: better discriminative power to detect differences along all spectrum of performance and age.

This study presents limitations that should be acknowledged. The sample was cross-sectional and because of that all the age-related results cannot be taken as longitudinal as the true longitudinal invariance was not tested. The sample number was large and randomly selected from a larger one pertaining to three different places in Portugal, thus expecting to be representative of the common child, adolescent, and young adult, but further cross-cultural studies involving other countries are warranted for generalization.

Because metric and structural invariance were not proved along the age groups, caution should be used when calculating sub-scales and total MCA scores. Factor scores or weighted average scores are to be tested, according to the different age models findings, to determine the more appropriate way for sub-scales and total MCA scoring.

Finally, and because the intention of the MCA is to address the full spectrum of lifelong motor competence, the results at different age periods should be matched against pre-existent motor scales that are proxy to the motor competence trait, and to more complex and combined movement skills like the one used in specific sports skills.

## Conclusion

This study adds valuable information for the validation of the MCA as a useful instrument for assessing motor competence throughout the life cycle. The MCA model proved to fit well from early childhood to early adulthood. Meaningful changes within the model parts' relationships were found that reflect the developmental changes of the growing years, but the overall model constituents remained representing three MCA domains, the locomotor, stability and manipulative sub-scales. After these results, an MCA classification procedure for each sub-scale and for the total MCA can be proposed based on the characteristics found for each age group.

## Aknowledgments

The authors wish to acknowledge the substantial improvements to our work that resulted from the reviewers' suggestions and thorough comments.

## Disclosure of potential conflicts of interest

The authors declare that they have no competing interests.

## Funding

This work was supported by the Fundação para a Ciência e a Tecnologia [UIDB/00447/2020 (unit 447)]; Fundação para a Ciência e a Tecnologia [UID04045/2020]; Fundação para a Ciência e a Tecnologia [UID04045/2020]; Regional Operational Program North 2020 [Norte-01-0145-FEDER-000043]; Regional Operational Program North 2020 [Norte-01-0145-FEDER-000043].

## ORCID

Luis P. Rodrigues http://orcid.org/0000-0002-6804-3600
Carlos Luz http://orcid.org/0000-0002-9126-5375
Vitor P. Lopes http://orcid.org/0000-0003-1599-2180

## References

AAHPER. (1975). *Aahper youth fitness test manual*. American Alliance for Health, Physical Education, and Recreation.

Adolph, K. E., & Hoch, J. E. (2019). Motor development: Embodied, embedded, enculturated, and enabling. *Annual Review of Psychology*, *70*(1), 141–164. https://doi.org/10.1146/annurev-psych-010418-102836

Barnett, L. M., Van Beurden, E., Morgan, P. J., Brooks, L. O., & Beard, J. R. (2008). Does childhood motor skill proficiency predict adolescent fitness? *Medicine and Science in Sports and Exercise*, *40*(12), 2137–2144. https://doi.org/10.1249/MSS.0b013e31818160d3

Behan, S., Belton, S., Peers, C., O'Connor, N. E., & Issartel, J. (2019). Moving well-being well: Investigating the maturation of fundamental movement skill proficiency across sex in irish children aged five to twelve. *Journal of Sports Sciences*, *37*(22), 2604–2612. https://doi.org/10.1080/02640414.2019.1651144

Brunner, M., & Süβ, H.-M. (2005). SÜβ H-M. Analyzing the reliability of multidimensional measures: An example from intelligence research. *Educational and Psychological Measurement*, *65*(2), 227–240. https://doi.org/10.1177/0013164404268669

Byrne, B. (2006). *Structural equation modeling with eqs: Basic concepts, applications, and programming*. Lawrence Erlbaum Associates.

Duncan, M. J., Roscoe, C. M. P., Noon, M., Clark, C. C. T., O'Brien, W., & Eyre, E. L. J. (2019). Run, jump, throw and catch: How proficient are children attending english schools at the fundamental motor skills identified as key within the school curriculum? *European Physical Education Review*, *25*(2), 1356336X19888953. https://doi.org/10.1177/1356336x17724173

Fernandez-Santos, J. R., Ruiz, J. R., Cohen, D. D., Gonzalez-Montesinos, J. L., & Castro-Piñero, J. (2015). Reliability and validity of tests to assess lower-body muscular power in children. *Journal of Strength and Conditioning Research*, *29*(8), 2277–2285. https://doi.org/10.1519/JSC.0000000000000864

Gabbard, C. (2018). *Lifelong motor development* (7th ed.). Wolters Kluwer.

Gallahue, D. (1982). *Understanding motor development in children* (2nd ed.). John Wiley and Sons.

Gallahue, D. L., & Ozmun, J. C. (1995). *Understanding motor development: Infants, children, adolescents, adults*. Brown & Benchmark.

Goodway, J. D., Ozmun, J. C., & Gallahue, D., . L. (2019). *Understanding motor development: Infants, children, adolescents, adults*. Jones & Bartlett Learning.

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2013). Partial least squares structural equation modeling: Rigorous applications, better results and higher acceptance. *Long Range Planning*, *46*(1–2), 1–12. https://doi.org/10.1016/j.lrp.2013.01.001

Hancock, G. R., & Freeman, M. J. (2001). Power and sample size for the root mean square error of approximation test of not close fit in structural equation modeling. *Educational and Psychological Measurement*, *61*(5), 741–758. https://doi.org/10.1177/00131640121971491

Hardy, L. L., Barnett, L., Espinel, P., & Okely, A. D. (2013). Thirteen-year trends in child and adolescent fundamental movement skills: 1997-2010. *Medicine & Science in Sports & Exercise*, *45*(10), 1965–1970. https://doi.org/10.1249/MSS.0b013e318295a9fc

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, *43*(1), 115–135. https://doi.org/10.1007/s11747-014-0403-8

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Iivonen, S., Kaarina Sääkslahti, A., & Laukkanen, A. (2015). A review of studies using the körperkoordinationstest für kinder (ktk). *European Journal of Adapted Physical Activity*, *8*(2), 18–36. https://doi.org/10.5507/euj.2015.006

Kline, R. B. (2004). *Beyond significance testing: Reforming data analysis methods in behavioral research*. American Psychological Association.

Luz, C., Almeida, G., Rodrigues, L. P., & Cordovil, R. (2017). The evaluation of motor competence in typically developing children: A systematic review.

*Journal of Physical Education*, *28*(1), e2857. https://doi.org/10.4025/jphyseduc.v28i1.2857

Luz, C., Rodrigues, L. P., Almeida, G., & Cordovil, R. (2016). Development and validation of a model of motor competence in children and adolescents. *Journal of Science and Medicine in Sport*, *19*(7), 568–572. https://doi.org/10.1016/j.jsams.2015.07.005

MacCallum, R. C., Browne, M. W., & Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. *1*(2), 130–149.

Magistro, D., Piumatti, G., Carlevaro, F., Sherar, L. B., Esliger, D. W., Bardaglio, G., Magno, F., Zecca, M., & Musella, G. (2020). Psychometric proprieties of the test of gross motor development–third edition in a large sample of italian children. *Journal of Science and Medicine in Sport*, *23*(9), 860–865. https://doi.org/10.1016/j.jsams.2020.02.014

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation, and physical activity* (2 ed.). Human Kinetics.

Payne, V. G., & Isaacs, L. D. (1987). *Human motor development: A lifespan approach*. Mayfield Pub. Co.

Roberton, M. A., & Halverson, L. E. (1984). *Developing children–their changing movement: A guide for teachers*. Lea & Febiger.

Rodrigues, L. P., Bezerra, P., & Saraiva, L. (2005). Influência do meio (urbano e rural) no padrão de aptidão física de rapazes de viana do castelo, portugal. *Revista Portuguesa De Ciências Do Desporto*, *5*(1), 77–84. https://doi.org/10.5628/rpcd.05.01.77

Rodrigues, L. P., Luz, C., Cordovil, R., Bezerra, P., Silva, B., Camões, M., & Lima, R. (2019). Normative values of the Motor Competence Assessment (MCA) from 3 to 23 years of age. *Journal of Science and Medicine in Sport*, *22*(9), 1038–1043. https://doi.org/10.1016/j.jsams.2019.05.009

Rudd, J. R., Barnett, L. M., Butson, M. L., Farrow, D., Berry, J., Polman, R. C. J., & Sinigaglia, C. (2015). Fundamental movement skills are more than run, throw and catch: The role of stability skills. *PLOS ONE*, *10*(10), e0140224. https://doi.org/10.1371/journal.pone.0140224

Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation coefficients: Appropriate use and interpretation. *Anesthesia & Analgesia*, *126*(5), 1763–1768. https://doi.org/10.1213/ANE.0000000000002864

Stodden, D., Goodway, J., Langendorfer, S., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest*, *60*(2), 290–306. https://doi.org/10.1080/00336297.2008.10483582

Thelen, E. (1986). *Development of coordinated movement: Implications for early human development*. Dordrecht: Martinus Nijhoff.

Ulrich, D. A., & Sanford, C. B. (1985). *Test of gross motor development*. Pro-ed.

Utesch, T., & Bardid, F. (2019). Motor competence. In D. Hackfort, R. Schinke, & B. Strauss (Eds.), *Dictionary of sport psychology*. (pp. 186). Elsevier.

Wickstrom, R. L. (1970). *Fundamental motor patterns*. Lea & Febiger.

Winpenny, E. M., Smith, M., Penney, T., Foubister, C., Guagliano, J. M., Love, R., Clifford Astbury, C., Sluijs, E. M. F., & Corder, K. (2020). Changes in physical activity, diet, and body weight across the education and employment transitions of early adulthood: A systematic review and meta-analysis. *Obesity Reviews*, *21*(4), e12962. https://doi.org/10.1111/obr.12962

Wolf, E. J., Harrington, K. M., Clark, S. L., & Miller, M. W. (2013). Sample size requirements for structural equation models: An evaluation of power, bias, and solution propriety. *Educational and Psychological Measurement*, *76*(6), 913–934. https://doi.org/10.1177/0013164413495237