

Gross motor coordination and their relationship with body mass and physical activity level during growth in Children aged 8–11 years old: a longitudinal and allometric approach

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ABSTRACT

Background: Gross motor coordination (GMC) is fundamental to the harmonious development of physical skills during the growth of children. This research aimed to explore the developmental changes in GMC during childhood, having controlled for the differences in children's body size and shape using a longitudinal, allometric scaling methodology.

Methods: A total of 104 children from North-East Italy of third-fourth- and fifth-grade students and each participant were tested for three consequent years. Subjects performed the short version of *korperkoordinationstest fur kinder* (KTK3) and the anthropometric characteristics were simultaneously collected. The physical activity questionnaire (PAQ-C) was used to evaluate the weekly physical engagement.

Results: Ontogenetic multiplicative models suggested nonlinear associations with GMC across the children's developmental years. Linear physique was a significant predictor associated with the development of GMC across time. PAQ-C was significantly associated with GMC from 8 to 13 years old.

Conclusion: Growth does not respect linear trends. A greater lean body mass could be assessed as a reliable predictor of GMC in children. The crucial period of life to improve the GMC is 8–10 years, while stabilization becomes evident from 10 to 13 years.

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Additional Information and
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INTRODUCTION

Physical activity (PA) practice becomes crucial for the general development of children during growth phases whereas the ability to perform different motor action is defined motor competence (MC; *Henderson & Sugden, 1992*). In particular, the MC within childhood is often defined as gross motor coordination (GMC; *Robinson et al., 2015*) because reflects the ability to perform a range of fundamental movement skills (e.g., running, jumping, hopping) that are fundamental as achievements to satisfy the demands of home, sport, school, and the social environment interaction. The perception of MC could contribute to start and continue different training programs or sport activities in children maintaining adherence through years (*De Meester et al., 2016*). In turn, the development of GMC lead to more specialized movement sequences, such as sport-specific gestures (*Clarke & Metcalfe, 2002*) (e.g., throwing in basketball) and lifelong movement skills (e.g., cycling and swimming) (*Hulteen et al., 2015*). In fact, GMC, which requires large muscles for balance, limbs, and trunk movements, become essential to gain more complex movements also, useful after childhood (*van der Fels et al., 2019*). The achievement of GMC is not an automatic process but needs a planned education and practice (*MacNamara, Collins & Giblin, 2015*).

Barnett et al. (2016) suggesting that variables such as age, sex and weight status affect GMC while *Queiroz et al. (2020)* found a positive modulation and improvements of GCM (in addition to body mass index (BMI)) in young belonging to a family with a high socio-economic-status family that permit higher possibilities to access in environmental contexts, sports facilities or sports clubs. These results underline the connection between motor practice and central nervous system development (*Daivids, Button & Bennett, 2008*) where the evaluation of GMC is often used as an indirect measure of healthy development (*Barnett et al., 2016*). In fact, longitudinal research provides a profound overview of adaptations and evolution during tumultuous phase for body mass, weight, and gender hormonal modifications both for girls and boys (*Henrique et al., 2018; Lima et al., 2017*), whereas longitudinal studies with at least three measures separated by time provide a more rigorous interpretation of motor development (*Baxter-Jones, 2017*). It appears evident that early physical experiences and those timing and structured time are necessary to guarantee the development of basic movements that allow children to obtain practical skills (*MacNamara, Collins & Giblin, 2015*). Considering children during the growth phases, *Dos Santos et al. (2018)* and *Armstrong & Welsman (2019)* suggested an allometric multilevel modeling analysis between the years (longitudinal) starting a new analytical approach to developmental exercise assessment (*Aitkin, Anderson & Hinde, 1981*). Allometric permits to analyse height and body mass as two different covariates.

Further, *Dos Santos et al. (2018)* showing that GMC is influenced from Body mass ($p < 0.001$) and stature ($p < 0.001$) negatively and positively respectively. Suggesting that ectomorphic (more linear children) in their overall body shape, and less heavy, show the best GMC development across time.

Indeed, it permits to understand the influence of variables (*i.e.* age, body mass, etc.) within an allometric framework to feed a flexible and sensitive evaluation of exercise performance variables (Nevill *et al.*, 2009). For example, Lovecchio *et al.* (2019) and Giuriato *et al.* (2020), through allometric modeling, show that the optimal body shape associated with physical performance (lower limb explosive strength, trunk strength and endurance performance) is a linear physique: slim with a high level of lean body mass. Further, Dos Santos *et al.* (2018) suggested that leaner and physically fitter children tended to show better results of GMC. In point of this, de Niet *et al.* (2021) suggested that physical education (PE) teachers, trainer, coaches or physical educator need to be conscious of the level of affection of the growth on GMC. Moreover, previous studies identified the importance to evaluate the PA level as a precursor of GMC development of children because it could better predict the motivation to start different activities, the motivation to acquire different motor skills and maintaining adherence to the PA programs (Khodaverdi *et al.*, 2016; Hulteen *et al.*, 2020).

In children, the GMC were often assessed through the Körperkoordinationstest Für Kinder (KTK) that is a reliable and low-cost battery field tests (Kiphard & Schilling, 2007) consisting of four standardized measurements such as walking backwards, jumping sideways, moving sideways, and hopping for height. Recently, Novak *et al.* (2017) proposed a short version of standard KTK: the KTK3 that showed a strong correlation with the KTK scores ($r = 0.98$, $p < 0.001$). In particular, the KTK3 seems to be more applicable in sports and school settings because the hopping for height test is more time-consuming and with higher risk of injuries (*e.g.*, ankle sprain) than other sub-tests (Novak *et al.*, 2017; Platvoet *et al.*, 2020). Indeed, KTK3 administration time is about 10 min against 20 min of KTK (Novak *et al.*, 2017).

To the best of our knowledge, no previous studies investigated the relationship between KTK3 results and height and body mass using an allometric modelling that permits an accurate evaluation of children body shape and performance in accordance with their growth. We hypothesized that a better comprehension of the relationship between these variables could help PE teachers and sports trainers to better evaluate their children's capacities and propose the adequate activities to their real growth.

Thus, adopting allometric modeling to investigate in better manner the influence of body mass and height separately on GMC; the aim of this study was focused on a longitudinal investigation (three consecutive years) of the GMC levels within the relationships between height and body mass using the allometric scaling analyses and the relationship of PA level with the GMC development in samples of children aged from 8 to 11 years old.

MATERIALS AND METHODS

Participants and study design

Considering children during the growth phases, Dos Santos *et al.* (2018) and Armstrong & Welsman (2019) suggested an allometric multilevel modeling analysis between the years (longitudinal) starting a new analytical approach to developmental exercise assessment (Aitkin, Anderson & Hinde, 1981). This longitudinal study involved 104 children aged

8–11 years that were recruited from primary and middle schools in the north-west region of Italy from their PE teachers in the 2017. Every group were assessed for three consecutive years from 2017 to 2019. All groups that started evaluations at the beginning of October 2017 attended third, fourth, fifth, and sixth grade. The authors chose the month of October because the school had just begun, and children had not yet participated in PE program that could alter their performances. Children with known chronic cardiac, respiratory, neurological, or musculoskeletal disorders were excluded from the study while all those were physical active during PE classes and with a contextual medical certificate were included to the assessment. They have taken all the measures during the PE lessons as scheduled in the morning framework (8.00–12.00 AM). The study protocol, including each feature of the experimental design, was approved by the Institutional ethical boards of schools (Prot. 1523; Cod 123.1/6) in accord with the “World Medical Association Declaration of Helsinki” as revised in 2018. According to the consent, all participants were free to withdraw their participation at any time, *a priori*, signed by parents or legal guardians.

Procedure

Data collection, including demographic/anthropometric information (sex, age, body mass, height), were collected in a separate appointment before the test sessions using standardized techniques from the sport scientist specialists in accordance with PE teachers. The age of the children from the birth date was calculated and subsequently rounded down values (*World Health Organization, 2008*).

Anthropometrics

Height was measured through a portable stadiometer with a precision of ± 1 mm (Stadiometer Seca 213, Intermed S.r.l. Milan, Italy) with children in an upright position, barefoot placed slightly apart, arms extended, and head positioned in Frankfort plane. Body mass was assessed through a beam scale with a precision of ± 100 g (Seca 813: Intermed S.r.l., Milan, Italy), with children wearing light clothing, without shoes and stood upright at the center of the platform of the mass scale. Then, the Body Mass Index (BMI) were calculated using the formula: weight (kilograms)/height * height (meters).

Gross motor coordination

GMC was evaluated using a new and short version of the KTK battery (*Kiphard & Schilling, 2007*) with a test-retest reliability coefficient of 0.97 (*Kiphard & Schilling, 2007*). Further, KTK3 retains relatively high accuracy and presents the potential to minimize the risk of injury, such as ankle sprain, to children by removing the hopping for height component ($r = 0.98, p < 0.001$). So, the other three subtests combined involve, in total, 10 min increasing the practicality of the battery and the full compliance of children.

In particular, the KTK3 procedure applied consisting of three trials:

1. Walking backwards on balance beams (three different widths, 6, 4.5 and 3 cm): A maximum of 24 steps (eight per trial) were counted for each balance beam, which comprises a maximum of 72 steps (24 steps \times 3 beams) for this test.

2. Moving sideways as quickly as possible using two boxes (25 cm × 25 cm × 5.7 cm) per two times, transferring the first plate, stepping on it, etc. The number of relocations was counted and summed over two trials.
3. Jumping sideways over a board (60 cm × 4 cm × 2 cm) as many times as possible in 15 s per two times. The number of jumps over two trials was summed.

Trained supervisors carried out all assessments in the same gym school context. All participants receive a demonstration and verbal instruction for the KTK3 battery. The presence and collaboration of the curricular PE teachers were guaranteed to meet the students' confidence.

Physical activity questionnaire

PA was assessed using the Physical Activity Questionnaire for older children (PAQ-C) questionnaire Italian version (*Gobbi et al., 2016*). The PAQ, as the version of IPAQ for older children, have acceptable reliability (males, $r = 0.75$; females, $r = 0.82$) and convergent validity (*Crocker et al., 1997*) and the administration and scoring are based on a self-administered, 7-day recall questionnaire (nine items). The nine items were proposed as follow:

1. Physical activity in your spare time: Have you done any of the following activities in the past 7 days (last week; e.g. skipping, rowing, running, bicycling etc.)? If yes, how many times (from “no” to “seven times or more”)?
2. In the last 7 days, during your physical education (PE) classes, how often were you very active (playing hard, running, jumping, throwing)? From “I do not PE” to “always”
3. In the last 7 days, what did you do most of the time *at recess*? From “sat down” to “run and played hard most of the time”
4. In the last 7 days, what did you normally do *at lunch* (besides eating lunch)? From “sat down” to “run and played hard most of the time”
5. In the last 7 days, on how many days *right after school*, did you do sports, dance, or play games in which you were very active? From “none” to “five times”
6. In the last 7 days, on how many *evenings* did you do sports, dance, or play games in which you were very active? From “none” to “six or seven times”
7. *On the last weekend*, how many times did you do sports, dance, or play games in which you were very active? From “none” to “six or more times”
8. Which *one* of the following describes you best for the last 7 days? From “all or most of my free time was spent doing things that involve little physical effort” to “high very often did physical things in my free time”
9. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week. From “none” to “very often”

Collected data on participation in different activities and sports, effort during PE classes, and exercise during the past 7 days (lunch, outside school, evening, and weekend).

The average overall score (from one to five for all of the nine items, with five representing a very physically active lifestyle) was calculated to determine each subject's PAQ-C score.

Data and statistical analysis

Data were manually collected by two operators and then inserted in separated sheets supporting anthropometric data with raw data of KTK3. All students are managed with a personal code to guarantee anonymity and a quick resume to match the two subsequent measurements. An appropriate method of analyzing longitudinal (repeated measures) data is to adopt a multilevel modeling approach, an extension of ordinary multiple regression where the data have a hierarchical or clustered structure (measurements grouped at different levels). For example, the repeated measure data, where individuals are measured more than one occasion represents hierarchical or clustered structure. In this study, children assumed to be a random sample represent the level-2 units, with the children's repeated measurements recorded at three visit occasions, being the level-1 unit. After this longitudinal allometric approach, we assessed the influence of body mass on GMC.

Nevill et al. (1998) suggested using the ontogenetic multiplicative model (*Nevill et al., 1998*) where $y = \text{body mass}^{k_1} \cdot \text{stature}^{k_2} \exp(a_i + b_i \cdot \text{PA}) \cdot e_{ij}$. A modified approach that considers body mass, height, and PA was used to compare our purposes and assumptions. Our model consists in a log-linear multilevel regression expressed as reported below:

$$\text{Ln}(\text{KTK}_{ij}) = k_1 \cdot \log_e(\text{Body Mass}) + k_2 \cdot \log_e(\text{Height}) + a_i + b_i \cdot \text{PA} + \log_e(e_{ij}) \quad (1)$$

In the previous formula, k_1 and k_2 are the ontogenetic allometric coefficients; a_i and b_i can vary randomly from different children (level-2), and $\log_e(e_{ij})$ is assumed to have a constant error variance between visit occasions (level-1). The constant a_i can vary for different populations, such as the fixed factor gender, academic grade, and test through years.

All parameters of M1 were simultaneously estimated using complete maximum likelihood procedures implemented in the MLwiN (*Rasbash & Woodhouse, 1995*). These procedures are robust, efficient, and consistent optimizing the maximum likelihood if multicollinearity were present (*Hedeker & Gibbons, 2006*).

Additionally, the inverted body mass index (iBMI; $1,000/\text{BMI}$; cm^2/kg) was calculated ($\text{Height}^2/\text{weight}$) as a valid marker of subject's lean body mass and then a better predictor of percentage body fat (*Nevill & Holder, 1995; Nevill et al., 2011*). Since iBMI has a positive linear association with percentage lean body mass it can represent an index of it.

RESULTS

Multilevel modeling results are in [Table 1](#). The model suggested the absence of difference between sex (-0.001 ± 0.018 , $p = 0.522$). GMC has a nonlinear trend across the study years (see [Fig. 1](#)). Further, this model shows the ontogenetic scaling factors that best define children's body size/shape and their GMC evolution from 8 to 13 years of age. Body mass (-0.244 ± 0.045 , $p < 0.001$) and stature (0.644 ± 0.194 , $p = 0.0005$) parameter estimates are statistically significant, suggesting that inverted body mass index (iBMI), a measure of lean body mass, in their overall physique, and less heavy, demonstrate the best GMC development through years. PA (using PAQ-C) was significantly associated with GMC

Table 1 Multilevel results for gross motor coordination model based on class 3 (8-year) and male subjects.

Parameters	Level 1			
	Estimate B	± SE	Z-score	p-value
Intercept	0.009	0.002	4.50	<0.001
LnHeight	0.644	0.194	3.32	0.0005
LnBody Mass	-0.244	0.045	-5.42	<0.001
Physical Activity	0.52	0.012	43.33	<0.001
Sex (Female)	-0.001	0.018	-0.06	0.5222
Class 4	0.089	0.037	2.41	0.0081
Class 5	0.178	0.042	4.24	<0.001
Class 6	0.215	0.058	3.71	0.0001
Class 7	0.241	0.078	3.09	0.0010
Class 8	0.261	0.089	2.93	0.0017
Year of test 2018	0.083	0.027	3.07	0.0011
Year of test 2020	0.142	0.053	2.68	0.0037
Random variance components (random intercepts model)				
Level 1 (within individuals)				
Variance (eij)	0.009 ± 0.001			
Level 2 (between individuals)				
Variance (uij)	0.009 ± 0.002			

Note:

Male Subjects and Class 3 do not appear because they would be redundant Class 4 = 9-year; Class 5 = 10-year; Class 6 = 11-year; Class 7 = 12-year; Class 8 = 13-year.

changes from 8 to 13 years. The variance components show significant intra-individual differences in GMC changes through the years, different individual growth rates. Furthermore, GMC differs significantly from 8 to 13 years (Table 1).

The positive interaction between classes is significant, proposing that GMC development (trajectory over age) increases between the years (see Fig. 1).

DISCUSSION

The main goal of the study is to evaluate the trend of GMC during growth spurt according to the anthropometric characteristics (height and body mass) and PA level on three consecutive years of school. The research was based on subjects aged 8 and 11 years old that followed a longitudinal observational approach (aged 10 to 13 years old) and, to make the study more reliable, it was used a multilevel allometric modeling to reach our aim (Dos Santos et al., 2018). Our results showed that the GMC was positively influenced by higher lean body mass and showed an increase performance across years without any difference between sex. The authors considered the importance of knowing the GMC trend through allometric approach to avoid the misleading conclusion where the improvements are related to the children's growth (Giuriato et al., 2020; Sammoud et al., 2018). Moreover, the allometric scaling becomes the most robust approach (Eq. 1) to compare GMC with anthropometric characteristics within the growth path variation

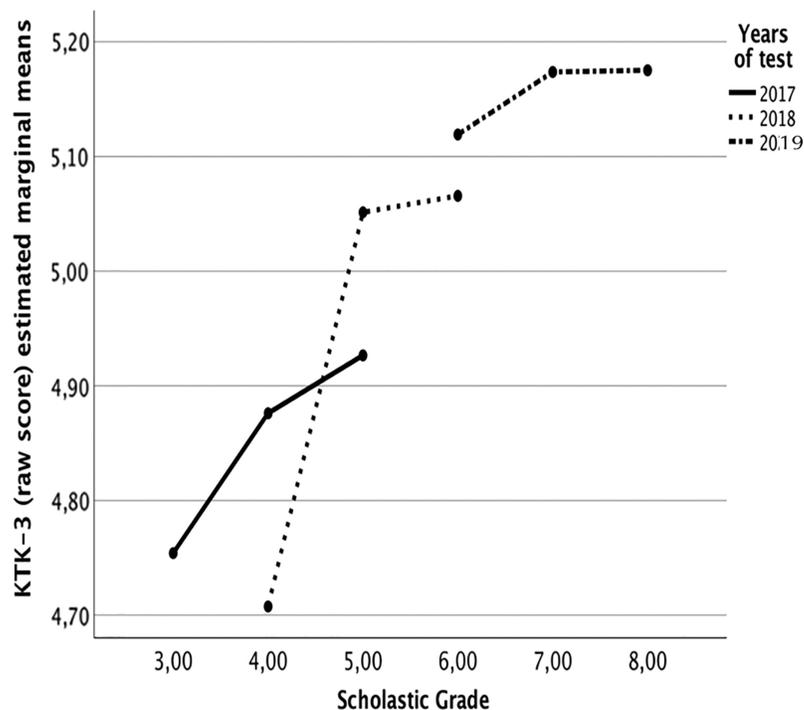


Figure 1 Estimated marginal means of KTK-3 test per age (at 2008) during the three longitudinal step assessments. Covariates appearing in the model are evaluated at the following $\text{LnHeight} = 0.3890$, $\text{LnMass} = 3.7431$. [Full-size](#) [DOI: 10.7717/peerj.13483/fig-1](https://doi.org/10.7717/peerj.13483/fig-1)

(Tsiotra et al., 2009). Indeed, the GMC increase in third, fourth and fifth academic grades, ergo from 8 to 10 years old respectively (*i.e.*, the age at which pre-adolescence begins) (Malina, Bouchard & Bar-Or, 2004), while remain constant in other grades that correspond to the beginning of adolescence (11, 12, 13 years old) (Fig. 1).

Based on multilevel modeling analyses, we found that children with linear physique perform better in GMC during growth. Indeed, the allometric approach explains that ectomorphic body shape, *i.e.*, slim, with low body fat, is the best body shape to develop GMC during growing, based on ratio $\text{Height}^{0.644} \cdot \text{Body mass}^{-0.244}$ (Estimated B column–Table 1). Our results demonstrated that lean body mass affects GMC across time. A proportional allometric model was applied to identify the influence of height and body mass. Multilevel modeling output across the years suggested a ratio, between the estimated B parameter, of 1:3 between height (0.644) and body mass (−0.244), respectively. This scaling method identified a tendency iBMI ratio between height and body mass (Table 1) with GMC: note that Nevill & Holder (1995) suggested that iBMI correspond to Lean Body Mass Index (LBM) because it has a positive linear association with percentage lean body mass ($\text{LBM}\% = 100 - \text{BF}\%$). Only one study investigating longitudinal GMC through allometric modelling (Dos Santos et al., 2018) and it did not wholly embrace our features. The authors identified the ectomorphic children as the optimal body shape for GMC outcomes suggesting that excess fat body mass negatively affected the performance. It may be possible that lean body mass promotes stabilization and propulsion of the body. Moreover, Faigenbaum (2000). showed that regular

participation in strength-training programs during childhood is an excellent predictor of motor skills improvement. Also, *de Souza et al. (2014)*, with a retrospective study, demonstrated that the children who were fitter and more active at 10 years old correspond to those with higher GMC at 6 years old. We could suppose that lean body mass may be a precursor of adequate GMC performance and motor skills. On the other side, *Dos Santos et al. (2018)* revealed a significant difference between gender, as opposed to the results of our study. These discrepancies could be explained by the different databases used for the allometric scaling: our data was based on a raw score of KTK3. Indeed, *Dos Santos et al. (2018)* have an already standardized dataset (*Kiphard & Schilling, 2007*) (MQ values) where the natural trend is described through the longitudinal data of the class between the years. Furthermore, the lack of differences between males and females underlies an interesting finding from a practical perspective (Estimated B parameter: -0.001 ; $p = 0.522$). When the coordination has been assessed, the differences between sex are alleviated. Children generally decline their GMC with age (*Giuriato et al., 2019*). *Dos Santos et al. (2018)* showed a nonlinear trend in GMC across time through allometric modelling, suggesting a performance peak at nine years old. In our features, the exponent of age square remained negative in all models. To avoid invasive analysis, the field test like KTK3, becomes a valuable way to verify the correct development of GMC. KTK3 could be considered a “physical tool” to indirectly evaluate the brain and motor system developments (*Latash, 2012*).

Our study found also that the PA level influenced the GMC (*Table 1*). The estimated parameter B (0.52) suggested a positive influence of the PA level (investigated using PAC-C questionnaire) on the GMC through the years ($p = 0.001$). This result is in line with *Giuriato et al. (2021)*, which highlighted that extra school hours of sports practice (*i.e.* PA) were the first predictor of performance. Considering an heterogeneous sample of subjects in their growth fase coming from school context, from a first view, the results about PA–GMC may seem obvious, because there is extensive documentation confirming that physical activity affects positively motor coordination (*de Souza et al., 2014*; *Fransen et al., 2014*). Indeed, adequate development of GMC through an satisfactory quantity of PA in youth may be important for the improvement and maintenance of health-related fitness from childhood to/into adolescence (*Stodden et al., 2014*). From another perspective, the Italian sample taking part in the study may not perform an adequate amount of physical activity GMC-based. In the light of this, allow opportunities to be physically active and build GMC during PE offering a valid possibility to children and adolescents to train in an appropriate manner (*Lai et al., 2014*; *Gao, Chen & Stodden, 2015*).

The KTK3 was composed of three items; two are based on jumping.

The strength of this longitudinal study is the allometric approach linked with multilevel modeling analyses and the use of KTK3 battery (*Vandorpe et al., 2011*). This study suggested some practical applications during the early stage of life. Firstly, during childhood, the trainer/PE teacher should be aware of the absence of differences between sex from 8 to 13 years old in GMC. Secondly, coaches should consider strong rationale during evaluation: sample-specific scaling model based on anthropometric characteristics

rather than theoretical models based on the assumption of body dimension similarity. Finally, the results suggest that this age group (third, fourth and fifth academic grade) has great potential to improve GMC in both sexes. Clearly, we cannot say whether this is the best niche (Gallahue & Ozmun, 2006). Considering this, an adequate PA level is essential to increase GMC, especially during the 8–10 years old period (third–fifth grade of school) as highlighted in Fig. 1 where the motor experiences modulate the patterns governing human movement (Brown-Lum et al., 2020; Wrisberg et al., 1995). This method is helpful for the first analyses. Still, the growth does not respect linear trends, and then a robust approach is necessary.

We are conscious that the study had some limitations such as the low numerosity of the enrolled sample and the evaluation of PA level through a questionnaire and not directly. Moreover, the body mass was calculated through IBMI and not considering perimeters and folds. But the substantial part of the study is the longitudinal approach through 3 years investigation and the multilevel modeling analyses that permit to evaluate the natural trend of GMC, based on a biological approach that accounting height and body mass, as two independent data.

Our results could contribute to ameliorate and finalize the GMC work of PE teachers and sports trainers during the growth of their children. In fact, the knowledge of the crucial period to develop GMC (aged 8 to 10 years old) and the relationship between GMC development with the body mass and PA level could help PE teachers and trainers to better evaluate their children capacities and, consequently, propose activities and training aimed to the correct development of children and their performances through different age and body shape.

CONCLUSIONS

In conclusion, our finding improved the features of previous literature that suggested an increase in fat body mass is negatively correlated with a rise in GMC level, indicating a positive association between lean body mass with GMC. Lean body mass could be evaluated as a good predictor of GMC in children, especially for teachers, trainers, or sport scientists in talent identification. Furthermore, the period between 8–10 years old is crucial to improve the GMC significantly and subsequently tend towards stabilization from 10 to 13 years old.

ADDITIONAL INFORMATION AND DECLARATIONS

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The authors received no funding for this work.

Competing Interests

The authors declare that they have no competing interests.

Author Contributions

- Matteo Giuriato conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.

- Nicola Lovecchio conceived and designed the experiments, performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Vittoria Carnevale Pellino performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Jan Mieszkowski analyzed the data, authored or reviewed drafts of the article, and approved the final draft.
- Adam Kawczyński performed the experiments, analyzed the data, authored or reviewed drafts of the article, and approved the final draft.
- Alan Nevill conceived and designed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Valentina Biino conceived and designed the experiments, performed the experiments, authored or reviewed drafts of the article, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (*i.e.*, approving body and any reference numbers):

This study was approved by the Institutional Ethical Boards of Schools (Prot. 1523; Cod 123.1/6).

Data Availability

The following information was supplied regarding data availability:

The raw data is available in the [Supplemental File](#).

Supplemental Information

Supplemental information for this article can be found online at <http://dx.doi.org/10.7717/peerj.13483#supplemental-information>.

REFERENCES

- Aitkin M, Anderson D, Hinde J. 1981.** Statistical modelling of data on teaching styles. *Journal of the Royal Statistical Society: Series A (General)* **144(4)**:419–448 DOI [10.2307/2981826](https://doi.org/10.2307/2981826).
- Armstrong N, Welsman JO. 2019.** Sex-specific longitudinal modeling of short-term power in 11- to 18-year-olds. *Medicine and Science in Sports and Exercise* **51(5)**:1055–1063 DOI [10.1249/MSS.0000000000001864](https://doi.org/10.1249/MSS.0000000000001864).
- Barnett LM, Lai SK, Veldman S, Hardy LL, Cliff DP, Morgan PJ, Zask A, Lubans DR, Shultz SP, Ridgers ND, Rush E, Brown HL, Okely AD. 2016.** Correlates of gross motor competence in children and adolescents: a systematic review and meta-analysis. *Sports Medicine (Auckland, N.Z.)* **46(11)**:1663–1688 DOI [10.1007/s40279-016-0495-z](https://doi.org/10.1007/s40279-016-0495-z).
- Baxter-Jones ADG. 2017.** Growth and maturation. In: Armstrong N, van Mechelen W, eds. *Oxford Textbook of Children's Sport and Exercise Medicine*. Third Edition. Oxford: Oxford University Press, 13–24.
- Brown-Lum M, Izadi-Najafabadi S, Oberlander TF, Rauscher A, Zwicker JG. 2020.** Differences in white matter microstructure among children with developmental coordination disorder. *JAMA Network Open* **3(3)**:e201184 DOI [10.1001/jamanetworkopen.2020.1184](https://doi.org/10.1001/jamanetworkopen.2020.1184).

- Clarke JE, Metcalfe JS. 2002.** The mountain of motor development: a metaphor. In: Clarke JE, Humphrey JH, eds. *Motor Development: Research and Reviews*. Vol. 2. Reston: National Association for Sport and Physical Education, 163–190.
- Crocker PR, Bailey DA, Faulkner RA, Kowalski KC, McGrath R. 1997.** Measuring general levels of physical activity: preliminary evidence for the physical activity questionnaire for older children. *Medicine and Science in Sports and Exercise* **29(10)**:1344–1349
DOI [10.1097/00005768-199710000-00011](https://doi.org/10.1097/00005768-199710000-00011).
- Dauids K, Button C, Bennett S. 2008.** *Dynamics of skill acquisition: a constraints led approach*. Champain: Human Kinetics.
- De Meester A, Stodden D, Brian A, True L, Cardon G, Tallir I, Haerens L. 2016.** Associations among elementary school children’s actual motor competence, perceived motor competence, physical activity and BMI: a cross-sectional study. *PLOS ONE* **11(10)**:e0164600
DOI [10.1371/journal.pone.0164600](https://doi.org/10.1371/journal.pone.0164600).
- de Niet M, Platvoet SWJ, Hoeboer JJAAM, de Witte AMH, de Vries SI, Pion J. 2021.** Agreement between the KTK3+ test and the athletic skills track for classifying the fundamental movement skills proficiency of 6-to 12-year-old children. *Frontiers in Education* **6**:571018
DOI [10.3389/feduc.2021.571018](https://doi.org/10.3389/feduc.2021.571018).
- de Souza MC, de Chaves RN, Lopes VP, Malina RM, Garganta R, Seabra A, Maia J. 2014.** Motor coordination, activity, and fitness at 6 years of age relative to activity and fitness at 10 years of age. *Journal of Physical Activity & Health* **11(6)**:1239–1247
DOI [10.1123/jpah.2012-0137](https://doi.org/10.1123/jpah.2012-0137).
- Dos Santos M, Nevill AM, Buranarugsa R, Pereira S, Gomes T, Reyes A, Barnett LM, Maia J. 2018.** Modeling children’s development in gross motor coordination reveals key modifiable determinants. An allometric approach. *Scandinavian Journal of Medicine & Science in Sports* **28(5)**:1594–1603 DOI [10.1111/sms.13061](https://doi.org/10.1111/sms.13061).
- Faigenbaum AD. 2000.** Strength training for children and adolescents. *Clinics in Sports Medicine* **19(4)**:593–619 DOI [10.1016/s0278-5919\(05\)70228-3](https://doi.org/10.1016/s0278-5919(05)70228-3).
- Fransen J, Deprez D, Pion J, Tallir IB, D’Hondt E, Vaeyens R, Lenoir M, Philippaerts RM. 2014.** Changes in physical fitness and sports participation among children with different levels of motor competence: a 2-year longitudinal study. *Pediatric Exercise Science* **26(1)**:11–21
DOI [10.1123/pes.2013-0005](https://doi.org/10.1123/pes.2013-0005).
- Gallahue D, Ozmun J. 2006.** *Understanding motor development: infants, children, adolescents, adults*. Sixth Edition. Boston: McGraw- Hill.
- Gao Z, Chen S, Stodden DF. 2015.** A comparison of children’s physical activity levels in physical education, recess, and exergaming. *Journal of Physical Activity & Health* **12(3)**:349–354
DOI [10.1123/jpah.2013-0392](https://doi.org/10.1123/jpah.2013-0392).
- Giuriato M, Kawczynski A, Mroczek D, Lovecchio N, Nevill A. 2021.** Allometric association between physical fitness test results, body size/shape, biological maturity, and time spent playing sports in adolescents. *PLOS ONE* **16(4)**:e0249626
DOI [10.1371/journal.pone.0249626](https://doi.org/10.1371/journal.pone.0249626).
- Giuriato M, Nevill A, Kawczynski A, Lovecchio N. 2020.** Body size and shape characteristics for Cooper’s 12 minutes run test in 11–13 years old Caucasian children: an allometric approach. *The Journal of Sports Medicine and Physical Fitness* **60(3)**:417–421
DOI [10.23736/S0022-4707.19.10282-4](https://doi.org/10.23736/S0022-4707.19.10282-4).
- Giuriato M, Pugliese L, Biino V, Bertinato L, La Torre A, Lovecchio N. 2019.** Association between motor coordination, body mass index, and sports participation in children 6–11 years old. *Sport Sciences for Health* **15(2)**:463–468 DOI [10.1007/s11332-019-00554-0](https://doi.org/10.1007/s11332-019-00554-0).

- Gobbi E, Elliot C, Varnier M, Carraro A. 2016.** Psychometric properties of the physical activity questionnaire for older children in Italy: testing the validity among a general and clinical pediatric population. *PLOS ONE* **11(5)**:e0156354
DOI [10.1371/journal.pone.0156354](https://doi.org/10.1371/journal.pone.0156354).
- Hedeker D, Gibbons RD. 2006.** *Longitudinal data analysis*. Vol. 451. Hoboken: John Wiley & Sons.
- Henderson S, Sugden D. 1992.** *Movement assessment battery for children*. London: The Psychological Corporation.
- Henrique RS, Bustamante AV, Freitas DL, Tani G, Katzmarzyk PT, Maia JA. 2018.** Tracking of gross motor coordination in Portuguese children. *Journal of Sports Sciences* **36(2)**:220–228
DOI [10.1080/02640414.2017.1297534](https://doi.org/10.1080/02640414.2017.1297534).
- Hulteen RM, Barnett LM, True L, Lander NJ, Del Pozo Cruz B, Lonsdale C. 2020.** Validity and reliability evidence for motor competence assessments in children and adolescents: a systematic review. *Journal of Sports Sciences* **38(15)**:1717–1798
DOI [10.1080/02640414.2020.1756674](https://doi.org/10.1080/02640414.2020.1756674).
- Hulteen RM, Lander NJ, Morgan PJ, Barnett LM, Robertson SJ, Lubans DR. 2015.** Validity and reliability of field-based measures for assessing movement skill competency in lifelong physical activities: a systematic review. *Sports Medicine (Auckland, N.Z.)* **45(10)**:1443–1454
DOI [10.1007/s40279-015-0357-0](https://doi.org/10.1007/s40279-015-0357-0).
- Khodaverdi Z, Bahram A, Stodden D, Kazemnejad A. 2016.** The relationship between actual motor competence and physical activity in children: mediating roles of perceived motor competence and health-related physical fitness. *Journal of Sports Sciences* **34(16)**:1523–1529
DOI [10.1080/02640414.2015.1122202](https://doi.org/10.1080/02640414.2015.1122202).
- Kiphard EJ, Schilling F. 2007.** *Körperkoordinationstest für Kinder. 2. Überarbeitete und ergänzte Auflage*. Weinheim: Beltz Test GmbH.
- Lai SK, Costigan SA, Morgan PJ, Lubans DR, Stodden DF, Salmon J, Barnett LM. 2014.** Do school-based interventions focusing on physical activity, fitness, or fundamental movement skill competency produce a sustained impact in these outcomes in children and adolescents? A systematic review of follow-up studies. *Sports Medicine* **44(1)**:67–79
DOI [10.1007/s40279-013-0099-9](https://doi.org/10.1007/s40279-013-0099-9).
- Latash ML. 2012.** *Fundamentals of motor control*. Amsterdam: Elsevier Science Publishing Co Inc.
- Lima RA, Bugge A, Pfeiffer KA, Andersen LB. 2017.** Tracking of gross motor coordination from childhood into adolescence. *Research Quarterly for Exercise and Sport* **88(1)**:52–59
DOI [10.1080/02701367.2016.1264566](https://doi.org/10.1080/02701367.2016.1264566).
- Lovecchio N, Giuriato M, Zago M, Nevill A. 2019.** Identifying the optimal body shape and composition associated with strength outcomes in children and adolescent according to place of residence: an allometric approach. *Journal of Sports Sciences* **37(12)**:1434–1441
DOI [10.1080/02640414.2018.1562615](https://doi.org/10.1080/02640414.2018.1562615).
- MacNamara Á, Collins D, Giblin S. 2015.** Just let them play? Deliberate preparation as the most appropriate foundation for lifelong physical activity. *Frontiers in Psychology* **6(964)**:1548
DOI [10.3389/fpsyg.2015.01548](https://doi.org/10.3389/fpsyg.2015.01548).
- Malina RM, Bouchard C, Bar-Or O. 2004.** *Growth, maturation, and physical activity*. Second Edition. Champaign: Human Kinetics.
- Nevill AM, Holder RL. 1995.** Body mass index: a measure of fatness or leanness? *The British Journal of Nutrition* **73(4)**:507–516 DOI [10.1079/BJN19950055](https://doi.org/10.1079/BJN19950055).

- Nevill AM, Holder RL, Baxter-Jones A, Round JM, Jones DA. 1998. Modeling developmental changes in strength and aerobic power in children. *Journal of Applied Physiology (Bethesda, Md. : 1985)* 84(3):963–970 DOI 10.1152/jappl.1998.84.3.963.
- Nevill AM, Stavropoulos-Kalinoglou A, Metsios GS, Koutedakis Y, Holder RL, Kitas GD, Mohammed MA. 2011. Inverted BMI rather than BMI is a better proxy for percentage of body fat. *Annals of Human Biology* 38(6):681–684 DOI 10.3109/03014460.2011.606832.
- Nevill A, Tsiotra G, Tsimeas P, Koutedakis Y. 2009. Allometric associations between body size, shape, and physical performance of Greek children. *Pediatric Exercise Science* 21(2):220–232 DOI 10.1123/pes.21.2.220.
- Novak AR, Bennett KM, Beavan A, Pion J, Spiteri T, Franssen J, Lenoir M. 2017. The applicability of a short form of the körperkoordinationstest für kinder for measuring motor competence in children aged 6 to 11 years. *Journal of Motor Learning and Development* 5(2):227–239 DOI 10.1123/jmld.2016-0028.
- Platvoet S, Pion J, de Niet M, Lenoir M, Elferink-Gemser M, Visscher C. 2020. Teachers' perceptions of children's sport learning capacity predicts their fundamental movement skill proficiency. *Human Movement Science* 70(5):102598 DOI 10.1016/j.humov.2020.102598.
- Queiroz D, Aguilar JA, Martins Guimarães TG, Hardman CM, Lima RA, Duncan MJ, Santos M, de Barros M. 2020. Association between body mass index, physical activity and motor competence in children: moderation analysis by different environmental contexts. *Annals of Human Biology* 47(5):417–424 DOI 10.1080/03014460.2020.1779815.
- Rasbash J, Woodhouse GM. 1995. *MLn command reference: version 1.0*. London: University of London, Institute of Education, Multilevel Models Project.
- Robinson LE, Stodden DF, Barnett LM, Lopes VP, Logan SW, Rodrigues LP, D'Hondt E. 2015. Motor competence and its effect on positive developmental trajectories of health. *Sports Medicine* 45(9):1273–1284 DOI 10.1007/s40279-015-0351-6.
- Sammoud S, Nevill AM, Negra Y, Bouguezzi R, Chaabene H, Hachana Y. 2018. Allometric associations between body size, shape, and 100-m butterfly speed performance. *The Journal of Sports Medicine and Physical Fitness* 58(5):630–637 DOI 10.23736/S0022-4707.17.07480-1.
- Stodden DF, Gao Z, Goodway JD, Langendorfer SJ. 2014. Dynamic relationships between motor skill competence and health-related fitness in youth. *Pediatric Exercise Science* 26(3):231–241 DOI 10.1123/pes.2013-0027.
- Tsiotra GD, Nevill AM, Lane AM, Koutedakis Y. 2009. Physical fitness and developmental coordination disorder in Greek children. *Pediatric Exercise Science* 21(2):186–195 DOI 10.1123/pes.21.2.186.
- van der Fels I, Smith J, de Bruijn A, Bosker RJ, Königs M, Oosterlaan J, Visscher C, Hartman E. 2019. Relations between gross motor skills and executive functions, controlling for the role of information processing and lapses of attention in 8–10 year old children. *PLOS ONE* 14(10):e0224219 DOI 10.1371/journal.pone.0224219.
- Vandorpe B, Vandendriessche J, Lefevre J, Pion J, Vaeyens R, Matthys S, Philippaerts R, Lenoir M. 2011. The Körperkoordinationstest für Kinder: reference values and suitability for 6–12-year-old children in Flanders. *Scandinavian Journal of Medicine & Science in Sports* 21(3):378–388 DOI 10.1111/j.1600-0838.2009.01067.x.
- World Health Organization. 2008. Training course on child growth assessment. Geneva: WHO. Available at <https://www.who.int/publications-detail-redirect/9789241595070>.
- Wrisberg CA, Dale GA, Liu Z, Reed A. 1995. The effects of augmented information on motor learning: a multidimensional assessment. *Research Quarterly for Exercise and Sport* 66(1):9–16 DOI 10.1080/02701367.1995.10607651.