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Motor performance is not related to injury risk in growing elite-level male youth football players. A causal inference approach to injury risk assessment

Nikki Rommers[a,b,c], Roland Rössler[d,e,*], Ian Shrier[f], Matthieu Lenoir[b], Erik Witvrouw[g], Eva D'Hondt[a], Evert Verhagen[d]

[a] Department of Movement and Sport Sciences, Vrije Universiteit Brussel, Brussels, Belgium
[b] Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium
[c] Research Foundation – Flanders (FWO), Brussels, Belgium
[d] Amsterdam Collaboration on Health and Safety in Sports, Amsterdam UMC, Vrije Universiteit Amsterdam, Department of Public and Occupational Health, Amsterdam Movement Sciences, Amsterdam, The Netherlands
[e] Department of Sport, Exercise, and Health, University of Basel, Basel, Switzerland
[f] Centre for Clinical Epidemiology, Lady Davis Institute, Jewish General Hospital, McGill University, Montreal, Canada
[g] Department of Physical Therapy and Motor Rehabilitation, Ghent University, Ghent, Belgium

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ABSTRACT

Objective: To identify the causal relation between growth velocity and injury in elite-level youth football players, and to assess the mediating effects of motor performance in this causal pathway.
Design: Prospective cohort study.
Methods: We measured the body height of 378 male elite-level football players of the U13 to U15 age categories three to four months before and at the start of the competitive season. At the start of the season, players also performed a motor performance test battery, including motor coordination (Körperkoordinationstest für Kinder), muscular performance (standing broad jump, counter movement jump), flexibility (sit and reach), and endurance measures (YoYo intermittent recovery test). Injuries were continuously registered by the academies' medical staff during the first two months of the season. Based on the causal directed acyclic graph (DAG) that identified our assumptions about causal relations between growth velocity (standardized to cm/y), injuries, and motor performance, the causal effect of growth velocity on injury was obtained by conditioning on maturity offset. We determined the natural indirect effects of growth velocity on injury mediated through motor performance.
Results: In total, 105 players sustained an injury. Odds ratios (OR) showed a 15% increase in injury risk per centimetre/year of growth velocity (1.15, 95%CI: 1.05–1.26). There was no causal effect of growth on injury through the motor performance mediated pathways (all ORs were close to 1.0 with narrow 95%CIs).
Conclusions: Growth velocity is causally related to injury risk in elite-level youth football players, but motor performance does not mediate this relation.

Practical implications

- Monitoring growth velocity in young athletes should become part of a risk management strategy to identify individuals being in periods of higher injury risk.
- Screening of preseason motor performance measures does not allow assessing injury risk in the near future.
- This study does not provide evidence to specifically target general motor performance when aiming at injury prevention in pubertal elite-level football players.

1. Introduction

Injuries in youth academy football (soccer) are a risk for the careers of talented players. Therefore, injury risk assessment and

* Corresponding author.
E-mail address: Roland.Roessler@unibas.ch (R. Rössler).

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management are of great importance for youth academies to retain their high potential athletes. Injury incidence in elite-level football players increases with age and peaks during adolescence.[1] Injuries in this period have been associated with the adolescent growth spurt.[2,3]

In fact, injuries are the result of a complex interaction of different causal factors and one or more inciting events leading to tissue overload.[4] Effective injury risk management strategies must address factors with a causal relation to the injury and not just factors associated with injury.[4] In order to understand the complex relationships between causal risk factors and injuries, it is necessary to broaden the approach of evaluating injury risk.

In adolescent football players, certain types of injuries occur during specific phases of growth and maturation.[3] Osgood Schlatter disease, for example, typically occurs during the adolescent growth spurt.[1] A high increase in body height has previously been associated with an increased risk of injury in male elite-level football players between 9 and 18 years of age.[2,5] The association between growth velocity (i.e. increase in body height over time) and injuries is one that lasts for only a short period of time.[2]

Growth is a non-linear process that occurs at an individual rate and is mainly genetically determined.[6] The expected growth velocity of adolescents is often described by the time to or from the peak height velocity.[6] The closer an individual is to his or her peak height velocity (i.e. the peak in growth velocity), the higher the expected growth velocities.[6] During adolescence, motor coordination, muscular performance, and endurance all undergo a marked development.[7] As such, practitioners believe these modifiable variables might serves as risk or protective factors for injuries during periods of fast growth and are thus treated as potential targets for injury risk reduction strategies.[8] Interestingly, flexibility is often cited as an injury risk factor, although no association has been reported,[9] and the effect of growth on flexibility remains controversial.[10]

Previous work has only investigated associations between growth velocity and injury[2,5] or between motor performance and injury[11,12] in youth elite-level football players. These studies did not apply analytical models based on causal concepts to determine injury risk, so no causal conclusions could be drawn. Furthermore, no previous study investigated the potential role of modifiable motor performance parameters in the growth-injury relationship. Therefore, the aim of this study was to use a causal inference approach to gain further insights in the causal effect of growth velocity on injury risk, and the role of motor performance measures as modifiable mediating factors in pubertal elite-level male youth football players.

2. Methods

We conducted a prospective study in elite-level youth football players, analysing the data of 378 male players of the U13-U15 age categories. Players were recruited from the youth academies of eight Belgian premier league football clubs. Before the start of the season, we informed parents and players about the risks and benefits upon participation. Parents then provided their written informed consent and players their written assent. All players with parental consent, who were not injured at the start of the season, were eligible for participation in this study. The study protocol was approved by the medical ethical committee of Vrije Universiteit Brussel (B.U.N. 143201628616) and measurements were performed according to the Declaration of Helsinki.

We describe a causal Directed Acyclic Graph (DAG) that makes our assumptions about the causal relationships between variables clear (Fig. 1).[13] Our graph includes growth velocity as the exposure of interest (top left), the potential motor performance mediators

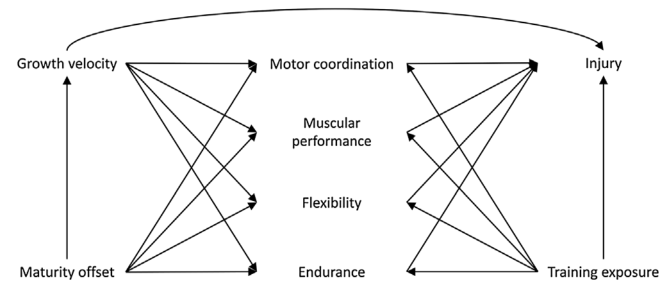

Fig. 1. Directed Acyclic Graph (DAG) of causal pathways investigated from growth velocity to injury event.

(middle) as well as covariates maturity offset and football exposure (bottom). We included the values of these mediators measured after the period over which growth velocity was assessed. This is because the causal effect of these mediators is considered to be due to their current status, without a lag period. In other words, if there are two participants who both have the same muscular performance, they are thought to have the same risk of injury regardless of how long they have been that strong. Since earlier measures are unrelated to current risk of injury, they do not have to be included in the causal DAG.

At the end of both the 2016–2017 and 2017–2018 competitive season (April–May), we measured the body height of players in the U12 to U14 age categories. At the start of the subsequent competitive season (i.e. August 2017 or August 2018, respectively), we collected data on height, sitting height, body mass, motor coordination, muscular performance, endurance, and flexibility. During the first two months of the competitive season, injuries and exposure were continuously monitored. The flow of participants, as well as the timeline of the measurements, are displayed in Appendix.

We measured body height to the nearest 0.1 cm. We standardized growth velocity to centimetre per year, by dividing the change in body height between the two measurements by the exact time in between those two measurements. Maturity offset refers to the time before or after the peak height velocity and was included in our analyses as a covariate.[14] An estimation of the maturity offset was calculated using a cross-validated prediction equation including the player's chronological age, body height, body weight (to the nearest 0.1 kg) and sitting height (to the nearest 0.1 cm, Harpenden sitting height table, Holtain, UK).[14]

We assessed generic motor coordination using the valid short version of the Körperkoordinationstest für Kinder test battery,[15] consisting of: (1) jumping sideways, the number of jumps over a wooden slat; (2) moving sideways, the number of displacements on wooden boards; (3) balancing backwards, the number of steps on 3 wooden beams of decreasing width. All three subtests were conducted according to the methods described by Kiphard and Schilling.[16] The total motor coordination score was defined as the sum of the three subtests scores.[15]

We measured flexibility using the sit and reach test as described in the Eurofit test battery.[17] This test is used to measure flexibility of the lower back and the posterior chain of the lower extremities. This measure was taken according to the standardised protocol with an accuracy of 0.5 cm.

A maximal YoYo Intermittent Recovery Test Level 1 (YYIR1) was conducted as described by Krustrup and colleagues.[18] This test consists of repeated running bouts performed at progressively increasing speeds, interspersed with active rest periods and is performed until the player is exhausted. The YYIR1 test was performed on artificial turf in dry weather conditions, wearing football shoes. In our analyses, we used the total distance (m) covered.

The standing broad jump was executed as described in the Eurofit test battery manual.[17] We applied the method described by Bosco et al.[19] and Castagna & Castellini[20] to measure counter movement jump height to the nearest 0.1 cm with the Optojump system (OptoJump System, Microgate, Italy). The test was executed three times in two conditions: without and with an arm swing. We used the best score in each condition for our analyses. We calculated an overall composite muscular performance score by summing the scores for standing broad jump, counter movement jump without arm swing, and counter movement jump with arm swing.

We defined a medical attention injury as any injury that required an assessment by medical or paramedical staff.[21] In the participating youth academies, all players who were unable to participate in training or match play, or who experienced any physical complaint, were required to see the academy's medical or paramedical staff. The injury mechanism, type, and location, as well as the date of injury and return to full participation were registered using a standardised registration form. The mechanism of injury was classified as either acute or overuse. An acute injury had a clear moment of onset, whereas an overuse injury did not.[21] We also provide frequencies of contact and non-contact injuries because this categorisation is of interest to coaches and clinicians. Since previous studies pointed out that the association between growth velocity and injuries is one of short duration,[2,5] we analysed the risk of a first injury occurring during the two months after the period over which growth velocity was assessed (i.e. August–September).

Individual football exposure was recorded by the teams' coaches in minutes. Attendance at training as well as individual playing time during matches were registered after each training session or match. We used the individual average weekly exposure before occurrence of the first injury in our analyses.

Descriptive statistics of individual player characteristics are presented as means (SD). We used the 'DAGitty' web application to draw the causal DAG in order to illustrate our assumptions about the causal relationships between growth velocity, motor performance and injury occurrence, and to guide our analytical strategy (Fig. 1).[22] The DAG guided our analytical strategy as to which variables we had to control for to minimise confounding when we assessed the total effect of growth velocity on injury and the effects mediated by the motor performance variables.

The occurrence of injuries during the first two months of the season (outcome measure in all analyses) was modelled using logistic regression and models were evaluated with the Hosmer and Lemeshow goodness of fit (GOF) test. According to our DAG (Fig. 1), an unbiased estimate for the total causal effect of growth velocity on injury can be obtained by including maturity offset (covariate) in the model. We also included average weekly football exposure (covariate) in the model, a determinant for injury risk, to increase the precision of the estimate. In further analyses, we estimated the total effect of the motor performance variables (predictor variables) on injury by including individual average weekly football exposure (covariate) in the model. The main outcome measure of our analyses were all medical attention injuries. We also conducted exploratory sub-group analyses based on acute injuries and overuse injuries only.

Four causal mediation analyses were performed to determine if the effects of the continuous exposure (i.e. growth velocity) on the outcome (i.e. injury occurrence) are mediated through the four motor performance variables (i.e. motor coordination, muscular performance, flexibility, and endurance) in our DAG. In brief, the total effect was decomposed into the natural direct (i.e. not mediated) and natural indirect effect (i.e. mediated). Natural direct effects capture what the effect of growth velocity on injury would be if we could eliminate the effect of growth velocity on the mediator (i.e. remove the arrow from growth velocity to the mediator in Fig. 1).[23] Natural indirect effects capture the effect of growth on injury that occurs because growth affects the mediator. We included four predefined mediators of motor performance measures. Coefficients of the natural direct effect and natural indirect effect were interpreted as odds ratios (OR) with their 95% confidence intervals (95%CI). In order to calculate the natural effects, the nested counterfactual outcomes (i.e. other possible values of growth velocity within the observed range) were imputed by fitted values based on the imputation model.[24] All analyses were performed in R (version 3.5.4). We used the 'medflex' package (version 0.6-6) to calculate the natural direct and indirect effects.

Table 1
Baseline descriptive values for the total sample.

	Mean (SD)	Range
Age (y)	13.1 (1.1)	11.6–14.9
Height (cm)	158.2 (9.2)	133.1–186.6
Weight (kg)	44.9 (8.5)	28.1–72.7
Sitting height (cm)	81.3 (4.9)	68.0–96.5
Maturity offset (y)	−0.8 (0.9)	−3.1 to 1.8
Growth velocity (cm/y)	6.4 (3.1)	−2.7 to 18.2
Motor coordination score	234.9 (21.6)	175.0–291.0
Flexibility (cm)	19.6 (6.2)	1.0–37.0
Endurance (m)	1402.7 (514.4)	200.0–3040.0
Standing Broad Jump (cm)	184.7 (17.6)	140.0–260.0
Counter Movement Jump (cm)	28.1 (4.7)	16.7–43.5
Counter Movement Jump with arm swing (cm)	33.4 (5.1)	21.2–54.5
Composite muscular performance score	246.3 (25.6)	179.4–338.2
Football exposure (min/week)	332.1 (41.7)	256.4–405.7

SD, standard deviation; y, year; cm, centimetre; kg, kilogram; m, metre; min, minutes.

3. Results

We followed 378 players with a mean age of 13.1 (1.1) years of whom 105 sustained an injury during the 17,717 h of football exposure. The injury incidence was 5.9 (95%CI: 4.9–7.2) injuries per 1000 h of football exposure. A total of 56 overuse injuries occurred, compared to 49 acute injuries. Baseline characteristics, motor performance scores, and average weekly exposure of the total sample are displayed in Table 1. A detailed overview of injuries by mechanism, injury type, location, and lay-off time is presented in Appendix.

The total causal effect of growth velocity on injury occurrence demonstrated a 15% increase in injury risk per cm of growth per year (OR 1.15, 95%CI: 1.05–1.26, $p = 0.003$, GOF: $X^2 = 11.35$, $p = 0.124$) (e.g. a 2.31 increase in odds for a player growing 6 cm in one year). For overuse and acute injuries, the ORs for the total effect were 1.09 (95%CI: 0.99–1.21, $p = 0.09$, GOF: $X^2 = 3.05$, $p = 0.931$) and 1.10 (95%CI: 0.99–1.22, $p = 0.07$, GOF: $X^2 = 10.14$, $p = 0.256$), respectively.

The total causal effect of growth velocity on injury was decomposed into the natural direct effect and the natural indirect effect through each of the predetermined mediators. Detailed results of the investigated pathways are displayed in Table 2. The point estimate of the direct effect for growth velocity on all injuries (i.e. with exclusion of the mediated pathways), overuse injuries or acute injuries, did not differ from the total effect. In addition, there was no causal effect of growth velocity on injury acting through any of the mediators (ORs ranging between 0.99 and 1.00, $p > 0.05$) (Table 2). None of the motor performance measures had by itself a significant effect on injury occurrence.

We ran the same models only including lower extremity injuries. Excluding the upper extremity injuries did not alter the results.

Table 2
Results of the four natural effects models. The ORs show the effect per centimetre of growth velocity.

Mediators	Direct effect of growth velocity on injury OR (95%CI)	Indirect effect of growth velocity on injury through the mediators OR (95%CI)	Total effect of mediator on injury OR (95%CI)
All injuries			
Motor coordination	1.15 (1.03–1.28)**	0.99 (0.98–1.01)	0.99 (0.98–1.01)
Muscular performance	1.15 (1.03–1.28)*	1.00 (0.99–1.01)	0.99 (0.98–1.00)
Flexibility	1.15 (1.04–1.27)**	1.00 (0.99–1.00)	1.00 (0.95–1.04)
Endurance	1.16 (1.01–1.33)*	0.99 (0.97–1.01)	1.00 (1.00–1.00)
Overuse injuries			
Motor coordination	1.09 (0.97–1.21)	0.99 (0.98–1.01)	0.99 (0.98–1.01)
Muscular performance	1.09 (0.97–1.21)	1.00 (0.99–1.01)	0.99 (0.98–1.00)
Flexibility	1.10 (0.99–1.20)	1.00 (0.99–1.01)	0.98 (0.93–1.03)
Endurance	1.13 (0.97–1.30)	0.99 (0.97–1.02)	1.00 (1.00–1.00)
Acute injuries			
Motor coordination	1.09 (0.96–1.25)	1.00 (0.99–1.02)	1.00 (0.99–1.02)
Muscular performance	1.09 (0.96–1.23)	1.00 (0.99–1.01)	1.00 (0.99–1.01)
Flexibility	1.09 (0.96–1.23)	1.00 (0.99–1.01)	1.02 (0.97–1.07)
Endurance	1.08 (0.91–1.27)	1.00 (0.98–1.01)	1.00 (1.00–1.00)

OR = odds ratio; 95%CI = 95% confidence interval.
* $p < 0.05$.
** $p < 0.01$.

4. Discussion

The results of this study indicate a positive causal relation between growth velocity and injury risk among adolescent, elite-level youth football players. None of the assessed motor performance characteristics mediated the causal effect, or was identified as a risk factor in itself.

A growth velocity of 0.6 cm/month has previously been indicated as an injury risk factor in youth elite-level football players.[2] In the current study, we identified the continuous measure of growth velocity as a risk factor for injuries in adolescent elite-level football players, after adjusting for the player's maturity offset as a potential confounder. This finding indicates an increased risk of injury during the entire adolescent period that is not only associated with the peak of the growth spurt. We measured body height twice over a period of three to four months. This means that we were not able to capture short spikes in growth velocity, as was the case in the study of Kemper and colleagues.[2] However, growth measures over shorter periods of time were within the measurement error of the stadiometer in the past.[6] Although measurement errors were observed in our study (negative growth rate in two players, see Table 1), most changes were not within the error margin.

The general motor performance characteristics (i.e. motor coordination, muscular performance, flexibility, and endurance) we studied as risk factors and as mediators are often the targets of interventions .[8] In line with previous studies,[9,11,25] we did not find evidence that any of these motor performance parameters has an effect on injuries, nor that they mediate the causal effect of growth velocity on injuries. Our results do not infer that changes in motor performance over the growth period are completely unimportant regarding injury risk. Motor performance changes rapidly around the adolescent growth spurt,[7] and it might be the (in)ability of the player to adapt to this rapid change that finally affects injury risk. There are also other potential factors mediating or moderating the causal effect of general motor performance and injuries, such as risk-taking behaviour. For example, strength is considered a protective factor for injuries, but stronger players might engage in more risk-taking behaviour increasing their risk of injury[26] and thus keeping the overall injury risk the same. Had they maintained the same style of play, the risk would have decreased.

Our exploratory analyses regarding overuse and acute injuries showed the same direction of the effects but the uncertainty was greater due to reduced sample size (i.e. lower power). None of the general motor performance test outcomes had a mediating effect on the causal effects in the subgroup analyses. Several theories have been suggested to explain growth-related overuse injuries, going from imbalances in flexibility and strength,[27] to growing pains unrelated to physical activity.[28] Our results seem to support the latter. Overuse injuries have also been associated with a high individual training load,[29] which we did not assess in this study. The incidence of acute injuries is thought to increase around the adolescent growth spurt due to the motor awkwardness phenomenon, which is a temporary impairment of motor coordination.[30] This short-term phenomenon possibly only affects very specific motor coordination measures that were not captured in our motor performance test battery.

We examined general motor performance test outcomes as risk and mediating factors. It is possible that more specific strength tests, such as unilateral jumping assessments, are more likely to be associated with the risk of injury. Future research could focus on a larger variety of motor performance measures and examine these with potential moderating factors, such as training load. Modifying training load during adolescence is a commonly used risk management strategy in practice. Hence, future studies could look at load quantities and load tolerance changes at given growth velocities to develop practical recommendations for managing the injury risk during periods of rapid growth.

This is the first study applying a causal inference approach to evaluate the effect of growth velocity and motor performance on the risk of injuries. As with all studies, there are some limitations. We only used a limited number of field tests to measure the constructs motor coordination, muscular performance, flexibility, and endurance. Integration of more field measures, combined with lab tests, could potentially provide deeper insights to better understand the causality of injuries. Furthermore, the participants in this study are all highly selected youth players, competing in the country's highest league. The lower range of motor performance skills in the elite-level players (who are selected based on these skills) can also make it harder to find factors with sufficient potential to discriminate between players of higher or lower risk of injury.

5. Conclusion

Higher growth velocities were causally related to an increased risk of medical attention injuries in our sample of U13 to U15 male youth elite-level football players. The motor coordination, muscular performance, flexibility, and endurance measures used in this study did not appear to mediate this causal effect and were not risk factors of injuries themselves. Future studies could build upon our findings and investigate further possible causal pathways from general motor performance to injury risk, in order to identify specific targets for injury risk management in growing athletes.

Declaration of interest

None.

Author contribution statement

ED, ML, EW, and NR designed the overall project and prepared the funding application. NR, RR, IS, and EV designed the research question, NR and IS designed the methodology, NR conducted the analysis under supervision of IS; NR collected the data and RR contributed to the data collection. NR wrote the manuscript. All authors reviewed the manuscript.

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Appendix

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2021.03.004.

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