Research Quarterly for Exercise and Sport

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/urqe20

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To cite this article: Benjamin Holfelder & Nadja Schott (2022) Object Control Skill Performance Across the Lifespan: A Cross Sectional Study, Research Quarterly for Exercise and Sport, 93:4, 825-834, DOI: 10.1080/02701367.2021.1924351

To link to this article: https://doi.org/10.1080/02701367.2021.1924351

Published online: 15 Nov 2021.

RESEARCH QUARTERLY FOR EXERCISE AND SPORT
2022, VOL. 93, NO. 4, 825–834
https://doi.org/10.1080/02701367.2021.1924351

Object Control Skill Performance Across the Lifespan: A Cross Sectional Study

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ABSTRACT

Purpose: Studies on object control skills (OCS) have described changes in movement patterns over time, but mostly in children and adolescents, young adults, *or* older adults. Most of these studies focused on only one skill and usually only on the process- *or* product-oriented outcomes. Thus, this study aimed to explore OCS performance in children, younger adults, and older adults. **Methods**: A total of 120 male participants took part in this study, including 78 primary school children (7.96 ± 1.22 years), 22 young adults (23.5 ± 2.34 years), and 20 older adults (69.5 ± 4.43 years). We assessed the process-oriented performance of throwing, kicking, and catching performance using the component approach. Throwing and kicking velocity was recorded with a STALKER SOLO 2.0 radar gun. For catching, the number of caught balls was assessed. **Results**. Young adults had the highest component levels in all OCS; they also produced significantly higher throwing and kicking velocities than children and older adults. The proportion of participants achieving mastery or advanced skill proficiency varied significantly in children (6.4–32.1%), young adults (63.6–100.0%), and older adults (10.0–95.0%). With few exceptions, the results showed mainly moderately significant correlations between developmental levels and throwing/kicking velocity or number of successfully caught balls for all age groups. **Conclusion**: Our data indicate that children in particular rarely demonstrate advanced OCS and that there is a decrease in throwing and kicking but not in catching in older adults compared to the younger age groups.

ARTICLE HISTORY
Received 22 September 2020
Accepted 23 April 2021

KEYWORDS
Throwing; kicking; catching; process- and product-oriented assessment; children; young adults; older adults

In view of rising life expectancy and the increasing proportion of older adults within the population, maintaining the health of older people is becoming increasingly urgent. A key factor is preserving motor and cognitive performance (Herold et al., 2018). The selection of adequate movements and their correct execution are essential aspects for maintaining the individuals' health and autonomy for as long as possible. The ability to do this skillfully (accurately, automatically, and without great cognitive effort) means that we can work effectively, live independently, and interact efficiently and safely with our environment. However, there are stages in life when our abilities and skills are of lower quality compared to the years when they are optimal. These include the childhood years when, among other things, growth spurts of a physical, motor, and cognitive nature can significantly affect the quality of our motor performance, and later in life, when our motor and cognitive performance become less efficient (Schott & Klotzbier, 2018).

Development of object control performance

One aspect of motor performance examined in the literature is the performance of object control skills (OCS; e.g., throwing, kicking, and catching). These goal-directed movement patterns are regarded as building blocks for more advanced movements required for successful participation in ball games (e.g., football, handball, basketball) (Clark & Metcalf, 2002). The assessment of these skills may differ according to whether the movement uses a process-oriented (quality of movement) or product-oriented (outcome of the movement) assessment. Process-oriented assessments evaluate how a movement is performed and describe qualitative movement patterns; one example would be developmental sequences based on a component analysis (Halverson et al., 1982; Langendorfer & Roberton, 2002; Roberton & Halverson, 1984; Strohmeyer et al., 1991). Developmental sequences evaluate particular coordination patterns of individual components—so-called nodal points—of individual skills going from more crude and inefficient patterns of movement to more sophisticated and biomechanically efficient patterns of movement (Roberton & Halverson, 1984). Each process-oriented different component level is scored on an ordinal developmental scale (e.g., level 1–4), with higher levels corresponding to a more advanced movement pattern. Each component has three to four levels. In contrast, a product-oriented evaluation evaluates the result of a movement, which is typically determined as a quantitative score (e.g., throwing or kicking velocity or number of balls caught) (Haywood et al., 2012). According to previous research, the results of both approaches are correlated moderate to strong (Logan et al., 2017; True et al., 2017). To get a comprehensive view of the motor competence of an individual, Logan et al. (2017) recommend using both assessment approaches.

Published studies refer to age-related differences in component levels for throwing (Gromeier et al., 2017; Halverson et al., 1982; Langendorfer & Roberton, 2002; Lorson et al., 2013;

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Williams et al., 1990, 1991, 1998), kicking (Bloomfield et al., 1979), and catching (Haubenstricker et al., 1983; Strohmeyer et al., 1991). For example, a hypothetical lifespan developmental trajectory for process-oriented performance could be developed for the progression of throwing patterns from childhood to young adulthood, then to the regression in older adults. Halverson et al. (1982) showed that boys aged 6 to 13 years exhibited a linear development for trunk action, forearm action, and humeral action with increased levels and advanced performances from 0 to 46%, 0 to 41%, and 0 to 82%, respectively. Lorson et al. (2013) examined age-related differences in adolescents, young adults, and middle-aged adults and found that young adult men threw with significantly more advanced patterns compared with both the adolescent boys and adult men in the step action (28.6%, 55.2%, 26.1%), trunk action (32.1%, 57.7%, 13.0%), and humerus action (32.1%, 83.3%, 21.7%) components, but not in the forearm action (25.0%, 47.4%, 4.3%). A further regression can be found for older adults (Williams et al., 1990, 1991, 1998), who demonstrated that nine older male adults aged 63 to 78 years produced advanced levels for humerus action (31.9%) and foot action (97.9%), but not for forearm action (0%). Unfortunately, the number of studies on catching and kicking across the lifespan is quite limited. Bloomfield et al. (1979), who examined developmental changes in 56 boys aged 2 to 12 years as they performed a soccer kick for both force and accuracy, identified six groups concerning whole-body kicking patterns. The children exhibited a wide variation in kicking performance, which was probably attributed to experience rather than age (Scott et al., 2003). Haubenstricker et al. (1983) showed that 60% of boys aged 6 years of age exhibited an advanced level in catching. Another study examining developmental sequences for hands and body in children between 5 and 12 years found that approximately 80% in the oldest group adjusted their body position to the ball, but only 40% adjusted their hand position to a ball, which was thrown directly to them (Strohmeyer et al., 1991). To our knowledge, no study has examined developmental sequences of kicking or catching in older adults.

Research on changes across the lifespan in throwing and kicking outcomes related to velocity is scarce. Usually, only individual stages of life are taken into focus. A compilation of ball velocities from three different studies showed a consistent linear increase in maximum throwing velocity from 5 to 12 years with 12 m/s to 25 m/s (Burton & Rodgerson, 2003). Lorson et al. (2013) found throwing speeds of 23.7 m/s in adolescents, 29.4 m/s in young men, and 26.1 m/s in middle-aged men. Ball velocities in older adults of 16.6 m/s (Williams et al., 1991) were similar to the velocities produced by 8 to 9-year olds (Halverson et al., 1982). In a recent study, Vieira et al. (2018) examined kicking velocity in 366 young males between 8 and 20 years of age. Significant changes from 13.5 m/s in the youngest group to 27.4 m/s in the oldest group were observed. As of yet, no studies are looking at the development of kicking velocity beyond the young adult age.

Purpose of the study

Published studies on OCS have described changes in movement patterns over time, mostly in children and adolescents, young adults, *or* older adults. Most of these studies focused on only one skill and usually only on the process- *or* product-oriented outcomes. There is still a gap in the literature regarding the differences in OCS patterns and performance characteristics across the lifespan. In this study, we addressed two research questions: First, we examined process- and product-oriented performance of the OCS throwing, kicking, and catching across the life span. According to the findings of Lorson et al. (2013), we expect an increase in the process- and product-oriented OCS performance from childhood to young adulthood as a result of physical growth and exercise experience (Vallence et al., 2019) and a decrease in the process- and product-oriented OCS performance from young adulthood to old age due to physical deterioration with increasing age (Brook et al., 2016). Secondly, we examined the correlations between process- and product-oriented results of OCS. We expected moderate correlations between process- and product-oriented results within OCS (Logan et al., 2017; True et al., 2017), whereby factors such as body composition, in addition to the quality of movement, influence product-oriented results (Rodríguez-Lorenzo et al., 2016; Van den Tillaar & Ettema, 2004).

Methods

Participants

One hundred twenty male participants between the ages of 6 and 79 years were recruited and divided into six age groups, based on previous research investigating changes in the maturation and age-related effects of motor skill development (Duncan et al., 2019; Lorson et al., 2013; Williams et al., 1990, 1991, 1998): 1) Children, 1st, 2nd, 3rd, and 4th grade (CH1-4, 6–10 years, n = 78); 2) Young adults (YA, 20–27 years, n = 22), and 3) Older adults (OA, 62–79 years, n = 22). At primary school age, children receive structured physical education, and they increasingly have access to sports activities in clubs but rarely achieve mastery in key fundamental motor skills (Duncan et al., 2019). Young adulthood represents the age range in which the body has the highest performance capacity. There is a natural decline in physical performance in the age range between 60 and 80, but people still have access to sports activities and can live independently. We screened potential participants before they participated in the study and excluded them if they had physical or medical conditions preventing them from completing the tasks in the study, such as the inability to ambulate independently, dementia, significant loss of vision and/or hearing, current or history of neurological or psychiatric disorders, recent or anticipated medical procedures that may affect mobility.

Participants were recruited voluntarily from a middle-class social area, who were naive about the purpose of the experiment. Informed written consent was obtained before the beginning of testing. For children recruited from a regional elementary school, additional informed written consent was also provided from their parent or guardian. Participants were told that they could opt-out at any time. All procedures were in accordance to the Declaration of Helsinki (2013) with ethical standards, legal requirements, and international norms. The institutional ethics committee approved the project.

Test items and materials

Process- and product-oriented measures of OCS were assessed for three skills: throwing, kicking and catching.

Process-oriented assessment

We evaluated process-oriented OCS patterns using component developmental sequences for the overarm throw for force and catching (modified from Haywood & Getchell, 2014; Roberton & Halverson, 1984; Schott & Munzert, 2010; Strohmeyer et al., 1991) as well as a modified version for kicking for force (Bloomfield et al., 1979; Holfelder et al., 2013; Mally et al., 2011). The movement components for catching, throwing, and kicking are indicated in Tables 1–3, respectively.

Product-oriented assessment

Ball velocity of throwing and kicking was defined as the peak velocity after the release or the hit by the hand or foot measured by a radar gun (SOLO 2.0, STALKER, USA; unit: m/s). This method has been commonly used in standard field measurements (Weisberg et al., 2020). The radar gun was calibrated by the manufacturer with a maximum root-mean-squared error of 1.906 km/h. Peak ball velocity of throwing and catching was recorded for each trial, as well as the number/percentage of successfully caught balls.

Table 1. Developmental sequences within components for catching (modified after Haywood & Getchell, 2014).

Arm Action
AA 1: little response
AA 2: hugging. arms are extended sideways to encircle the ball
AA 3: scooping. Arms are extended forward but move under (scoop) the ball
AA 4: arms give. ball is caught in hands
Hand action
HA 1: palms up/down
HA 2: palms inward, the palms of the hands face each other
HA 3: palms adjusted, hands adjust to flight and size of the ball
Body action
BA 1: no adjustment
BA 2: swkward adjustment
BA 3: proper adjustment

Table 2. Developmental sequences within components for throwing for accuracy and force (modified after Haywood & Getchell, 2014; Schott & Munzert, 2010).

Step action
SA 1: no step
SA 2: homolateral step
SA 3: short contralateral step
SA 4: contralateral step with momentum
Trunk action
TA 1: no trunk action or forward or backward movements
TA 2: upper trunk rotation or total trunk ("block") rotation
TA 3: differentiated rotation
Preparatory arm backswing
PAB 1: no backswing
PAB 2: elbow and humeral flexion
PAB 3: circular, upward backswing
PAB 4: straight backswing
Arm & hand action
AA 1: humerus oblique, no forearm lag, low hand (pushing movement)
AA 2: humerus oblique, no forearm lag
AA 3: humerus aligned but independent, forearm lag, hand is behind the ball
AA 4: humerus lags; delayed forearm lag, finger momentum

Table 3. Developmental sequences within components of kicking for accuracy and force (Holfelder et al., 2013).

Approach—support leg position in relation to the ball
SLP 1: behind or in front (more than 1 foot length)
SLP 2: diagonally behind or in front (less than 1 foot length)
SLP 3: alongside
Backswing of the kicking leg (thigh)
BST 1: thigh is ahead of body
BST 2: thigh is in line with the trunk (extension)
BST 3: thigh is hyperextended
Backswing of the kicking leg (lower leg)
BSL 1: heel does not elevate to the height of the knee
BSL 2: heel reaches the height of the knee
BSL 3: heel elevates equal to or higher than the greater trochanter of the hip
Ball contact
BC 1: hit the ball with the toes
BC 2: hit the ball with an inside kick
BC 3: hit the ball with an instep kick
Upper trunk position during contact
TP 1: upper body leans back, hip flexed ("seated position")
TP 2: upper body leans back, hip extended
TP 3: upper body perpendicular to the ground
TP 4: upper body leans slightly over the ball
Arm action
AA 1: no arm movement or uncontrolled arm movements
AA 2: kicking leg and contralateral arm block upper body rotation ("jackknife movement")
AA 3: arms support balance (arms in high guard position)
AA 4: kicking leg and contralateral arm support upper body action

Other variables

Anthropometry. We measured height to 0.1 cm and body mass to 0.1 kg in all participants for descriptive purposes. Body mass index (BMI) was calculated as mass (kg) divided by height (m^2). According to BMI, the proportion of participants being underweight, normal or minimum overweight was based on well-established cut-points.

Procedures

Throwing

Throws were executed at indoor facilities using International Handball Federation (IHF) approved balls (size 0 [46–49 cm in circumference, 225–300 g in weight]: ≤ age 8; size 1 [50–52 cm in circumference, 425–475 g in weight]: age 8 to 12; size 2 [54–56 cm in circumference, 325–375 g in weight]: age 60–80; size 3 [58–60 cm in circumference, 290–330 g in weight]: age 20–30). At a distance of 4 m [height ≤ 120 cm], 4.5 m [height 120–140 cm] or 5 m [height ≥ 140 cm] in front of the ball, a large mat (5 × 4 m), which stood against a wall, was placed to absorb the momentum of the ball after the throw. A 0.5 × 0.5 m target was fixed on the middle of the mat starting 100 cm above the floor level. During the throws, the participants stood in a small area marked on the floor to allow video recording (frequency of 100 Hz) by two cameras placed to the right and front of each participant. Each participant performed five (children) or ten (adults, older adults) full-force throws with their preferred arm. Participants were instructed to throw as hard as they can. Trials in which the mat was not hit were counted but not analyzed.

Kicking

Kicks were executed at indoor facilities using Fédération Internationale de Football Association (FIFA) approved balls (size 3 [58–61 cm in circumference, 310–340 g in weight]: age 6–8; size 4 [64–66 cm in circumference, 310–370 g in weight]: age 9–11; size 5 [69–71 cm in circumference, 410–450 g in weight]: age ≥ 18). Seven meters in front of the ball, a large mat (5 × 4 m), which stood against a wall, was placed to absorb the ball's momentum after the kick. A 1.5 × 1.5 m target was drawn on the middle of the mat starting 20 cm above the floor level. It was intended that the target should model a successful penalty kick. The participants were filmed simultaneously from lateral views at 100 Hz using digital video cameras. The cameras were placed 1.5 m off the ground on tripods; the angles from the lateral cameras to participants were 90° and 45°, respectively. Each participant performed five (children) or ten (adults, older adults) full-force kicks with their preferred leg. Participants were instructed to kick as hard as they can. The approach run-up was standardized to one step. Trials in which the mat was not hit were counted but not analyzed.

Catching

Attempts were executed at indoor facilities using IHF approved balls (see throwing). At each trial, the participants had to produce a two-handed catch when a ball was manually thrown from a distance of 6 m toward the catcher. Each participant performed five (children) or ten (adults, older adults) trials. For a successful catch, the participant was given a score of 1. In case of an errant throw, the trial was repeated. One standard digital camera was positioned at a frontal viewpoint at 45°.

Data reduction and statistical analysis

Based on the recorded videos, two investigators categorized each trial using the movement component analysis approach (Roberton & Halverson, 1984; see Tables 1–3). The modal level across trials was used to represent that person's developmental level (Roberton & Halverson, 1984). Each component contained ranked developmental steps. The first developmental step was the least mature (in terms of motor performance) and was ascribed a score of 1; the next developmental step described a more mature skill level and received a 2. The scoring continued in this fashion until the most mature step was reached, which received the maximum score for the component. Scores for each component of a movement development sequence were added to ascribe the individual participant's score for the skill. The maximum values for throw, kick, and catch were 15, 20, and 10, respectively. A zero score was assigned when a participant did not perform the skill in a particular fashion (e.g., performed a one-handed catch or missed the target zone). If participants demonstrated all components of the skill, then they were rated as having "mastery"; if they demonstrated all but two (throwing), three (kicking), and one (catching) of the components of the skill, then "advanced skill proficiency" and if more than two/three/one component were deemed to be missing, then the participant was said to have no mastery of the skill. For all components of the three OCS, intra- and inter-rater reliability were, according to the guidelines of Koo and Li (2016), good to excellent. In other words, the results for the entire video rating obtained by the same evaluator of different trials (throwing ICC .92—.97; kicking ICC .85—.97; catching ICC .75—.89), or by two different evaluators, were comparable (throwing ICC .89—.99; kicking ICC .72—.99; catching ICC .88—.99). All videos were collected and rated by trained research assistants. Before the rating of all videos, each of the two raters rated the videos of five children. Differences between the two raters were thereafter discussed, and issues of ambiguity were discussed and clarified.

All statistical analyses were implemented on SPSS v.27 (SPSS, Chicago, IL). We first explored dependent variables to examine missing data points, normality of distributions, and presence of outliers. An alpha level of .05 was used for all statistical tests. Potential group differences for continuous variables (i.e., age, height, weight, BMI, product- and process-oriented results of OCS) were assessed using ANOVAs, and categorical variables (i.e., component analysis) were compared by chi-square test. Pearson's bivariate correlations among demographic and anthropometric variables, exercise duration, process- and product-oriented measures of OCS were calculated by age group. Correlation coefficients are interpreted according to Cohen's (1992) magnitude of effect sizes (small: $r = .10$; medium: $r = .30$; large: $r = .50$).

Results

Sample characteristics

The demographic characteristics of the 120 male participants are shown in Table 4. Less than 10% of the whole sample was obese (9.1% children, 5.0% older adults); however, 12.6% were underweighted (11.7% children, 4.5% adults, 35% older adults).

Motor performance

Throwing

The percentage of occurrence of each movement pattern for age is presented in Table 5. Children exhibited 42 of the 192 theoretical developmental profiles. By contrast, younger adults and older adults exhibited only 11 and 16 different profiles, respectively. The most common pattern among children was a step with the opposite leg (SA3/SA4), a block rotation of the trunk (TA2), elbow, and humeral flexion (PAB2). In contrast, younger adults exhibited an overall advanced level of throwing performance (step with the opposite leg, differentiated rotation, somewhat sufficient backswing, humerus, and delayed forearm lag). Older adults exhibit similar patterns compared to children; however, they exhibited better arm action.

Our chi-square post-hoc tests focused on component differences among age groups. When compared with the children group, the young adults performed at more advanced levels for the SA ($p = .006$), TA ($p < .001$), PAB ($p = .001$), and AA ($p = .001$). Young adults showed more advanced levels than the older adult group for the TA ($p = .021$) and AA ($p = .006$): however, no significant difference was found for the SA and PAB. Only for AA ($p = .012$), a significant difference existed when comparing the performance of the children and older adults to each other.

Table 4. Sample characteristics. Group means standard deviations.

	Children 1st grade n = 24	Children 2nd grade n = 17	Children 3rd grade n = 15	Children 4th grade n = 22	Children total n = 78	Younger Adults 20 to 27 years n = 22	Older adults 62 to 79 years n = 20	statistical analysis*
Age (years)	6.49 ± 0.36	7.67 ± 0.25	8.70 ± 0.61	9.29 ± 0.47	7.96 ± 1.22	23.5 ± 2.35	69.5 ± 4.43	F(5,114) = 2743, p < .001
Height (cm)	122 ± 4.31	132 ± 6.30	134 ± 5.61	142 ± 7.25	132 ± 9.61	184 ± 7.58	178 ± 5.63	F(5,114) = 362, p < .001
Weight (kg)	22.6 ± 2.76	29.0 ± 6.47	28.9 ± 5.14	34.6 ± 7.19	28.6 ± 7.19	79.0 ± 7.35	82.1 ± 12.1	F(5,113) = 272, p < .001
BMI (kg/m^2)	15.1 ± 1.40	16.5 ± 2.62	16.2 ± 1.71	17.0 ± 2.40	16.2 ± 2.17	23.5 ± 2.28	25.9 ± 3.62	F(5,113) = 68.6, p < .001

*One-way ANOVAs with children separated by grade.

Figure 1 shows the changes of the process- and product-oriented throwing performance as a function of developmental time. Univariate ANOVAs yielded significant effects of age on process-oriented performance, $F(5,114) = 10.9$, $p < .001$, $\eta^2_p = .324$, and on product-oriented performance, $F(5,114) = 76.2$, $p < .001$, $\eta^2_p = .770$. The main effect of age group, post-hoc tests (using Bonferroni-Holm correction) was performed to follow-up. There were significant differences between children from 1st and 2nd grade compared to 4th grade for product- and process-oriented measures. Young adults yielded better performance on the product-oriented measure than all children and older adults; however, there was no significant difference between 4th graders and young adults. Older adults showed significantly better results on the product-oriented measure than the 1st, 2nd, and 3rd graders, but on the process-oriented measure, there were only significant differences compared to the 1st graders. Partial correlations (controlled for height and weight) varied between $r = .10$ and $r = .80$, indicating moderate to strong relationships for process- and product-oriented performance in children and older adults (see Figure 1).

Kicking

The percentage of occurrence of each movement pattern for age is presented in Table 6. Children exhibited 47 (n = 78) of the theoretically 1296 developmental profiles. By contrast, younger adults (n = 22) and older adults (n = 20) exhibited 15 and 18 different profiles, respectively. The most common pattern among children was a support approach from behind (Step 1), an advanced level of the backswing of the thigh and lower leg, using an inside kick (Step 2), with the upper body leaning back, hip flexed (Step 1), and a "jackknife movement" (Step 2). Younger adults performed on almost all components on an advanced level, while older adults again performed similarly to the group of children.

Our chi-square post-hoc tests focused on component differences among age groups. When compared with the children group, the young adults performed more at advanced levels for the approach ($p < .001$), the ball contact ($p = .003$), the trunk movement ($p < .001$), and the arm action ($p < .001$). Young adults performed more advanced levels than the older adult group for the approach ($p = .001$), the backswing of the kicking leg—thigh ($p = .005$) and lower leg $p < .001$, and the arm action ($p = .032$), but no significant difference was found for ball contact and trunk movement. For the approach ($p = .002$), the kicking leg—lower leg ($p < .001$), and the trunk movement ($p < .001$), significant differences existed when comparing the performance of the children and older adults with better performances for boys.

Figure 2 shows the changes in process- and product-oriented kicking performance as a function of developmental time. Univariate ANOVAs yielded significant effects of age on process-oriented performance, $F(5,114) = 7.41$, $p < .001$, $\eta^2_p = .245$, and on product-oriented performance, $F(5,114) = 53.6$, $p < .001$, $\eta^2_p = .702$. The main effect of age group, post-hoc tests (using Bonferroni Holm correction) was performed to follow-up. There were no differences between 1st, 2nd, 3rd, and 4th graders for process-oriented measures, but for product-oriented measures (1st graders differed from all other children, 4th graders differed only compared to 1st and 2nd graders). Young adults yielded better performances than all children and older adults; older adults showed only significantly better results for the product-oriented measure than 1st graders. Partial correlations (controlled for height and weight) varied between $r = .11$ and $r = .63$, indicating a moderate to strong relationship for process- and product-oriented performance across the lifespan (see Figure 2).

Catching

The percentage of occurrence of each movement pattern for age is presented in Table 7. The most common pattern among younger and older adults was a proper adjustment to the oncoming ball with adjusted arms and hands, arms and body gave (AA4-HA3-BA3). Our chi-square post-hoc tests focused on component differences among age groups. Compared with the children group, younger and older adults performed at more advanced levels for all three components. Children displayed 11 out of 36 possible developmental profiles (older adults 3 out of 36). Less than 34% of all 1st to 3rd graders exhibited an advanced or mastery profile, while 55% of the 4th graders achieved an advanced or mastery profile in the catch.

Figure 3 shows the changes of the process- and product-oriented catching performance as a function of developmental time. Univariate ANOVAs yielded significant effects of age on process-oriented performance, $F(5,114) = 23.3$, $p < .001$, $\eta^2_p = .505$, and on product-oriented performance, $F(5,114) = 5.66$, $p < .001$, $\eta^2_p = .199$. The main effects of age and post-hoc tests (using Bonferroni Holm correction) were performed to follow-up. 3rd and 4th graders and younger and older adults outperformed the 1st graders, but they showed no differences compared to younger and older adults for product-oriented measures. Young and older adults yielded better performance on the product-oriented measure than all children; 1st and 2nd grade showed lower scores on product-oriented measures than 3rd and 4th graders. Partial correlations (controlled for height and weight) varied between .00 and .66, indicating only a moderate to strong relationship for process- and product-oriented performance in children and older adults (see Figure 3).

Table 5. Percentage of participants demonstrating each movement component of the overhead throw for accuracy and force, and mastery level by age group.

Component	Level	Children 1st grade [%]	Children 2nd grade [%]	Children 3rd grade [%]	Children 4th grade [%]	Children total [%]	Young adults [%]	Older adults [%]	statistical analysis*
Step action	SA 1	70.8	35.3	53.3	18.2	44.9	27.3	40.0	χ^2 (15) = 39.4,
	SA 2	8.3	17.6	0.0	9.1	9.0	4.5	5.0	p = .001
	SA 3	0.0	35.3	33.3	36.4	24.4	4.5	20.0	
	SA 4	20.8	11.8	13.3	36.4	21.8	63.6	35.0	
Trunk action	TA 1	20.8	41.2	6.7	4.5	17.9	4.5	10.0	χ^2 (10) = 57.6,
	TA 2	79.2	58.8	80.0	72.7	73.1	18.2	55.0	p < .001
	TA 3	0.0	0.0	13.3	22.7	9.0	77.3	35.0	
Preparatory arm backswing	PAB 1	8.3	5.9	0.0	0.0	3.8	0.0	10.0	χ^2 (15) = 35.2,
	PAB 2	83.3	82.4	93.9	50.0	75.6	40.9	55.5	p = .002
	PAB 3	8.3	11.8	6.7	40.9	17.9	31.8	20.0	
	PAB 4	0.0	0.0	0.0	9.1	2.6	27.3	15.0	
Arm action	AA 1	16.7	41.2	13.3	27.3	24.4	0.0	10.0	χ^2 (15) = 58.7,
	AA 2	33.3	17.6	6.7	13.6	19.2	0.0	5.0	p < .001
	AA 3	45.8	11.8	20.0	4.5	21.8	22.7	60.0	
	AA 4	4.2	29.4	60.0	54.5	34.6	77.3	25.0	
Mastery level									
mastery		0.0	0.0	0.0	4.5	1.3	18.2	0.0	χ^2 (10) = 38.9,
advanced skill proficiency		0.0	5.9	6.7	13.6	6.4	45.5	20.0	p < .001
non-mastery		100.0	94.1	93.3	81.8	92.3	36.4	80.0	

*Chi-square test with children separated by grade.

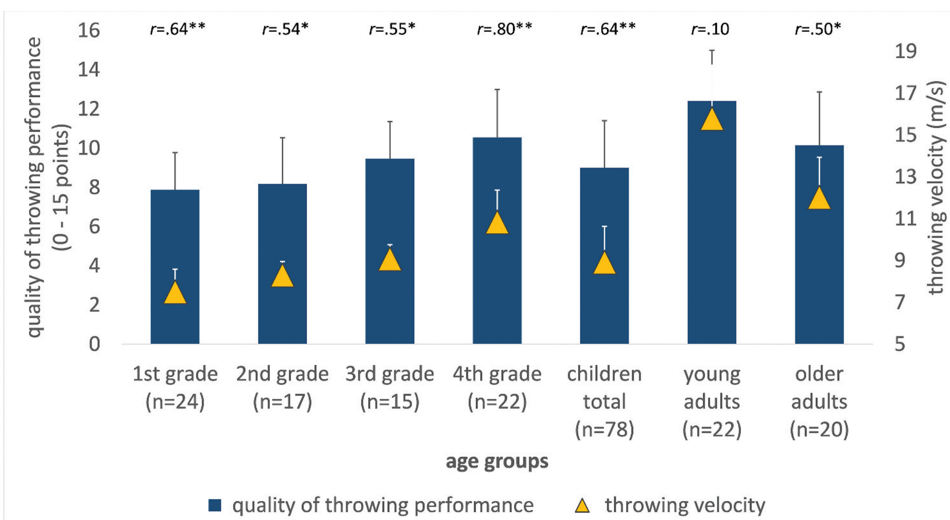

Figure 1. Means and standard deviations for process- and product-oriented throwing performance by age; correlation between process- and product-oriented measures by age group controlled for height and weight (* $p < .05$; ** $p < .01$).

Discussion

The overall objective was to examine the development and associations between process- and product-oriented measures of OCS in males across the lifespan. Specifically, this study aimed to analyze (1) the process- and product-oriented results for three OCS (throwing, kicking, and catching) in children, young and older adults, and (2) the correlations between process- and product-oriented results of these OCS for each age group.

Process-oriented assessments

Looking at the detailed process-oriented results (see Tables 5–7), it becomes apparent that the most significant proportion of mastery levels were achieved in the group of young adults, followed by older adults and children. These findings are in line with our expectations, as it is well known that the process-oriented aspects of a movement improve with physical development and experience from childhood to adulthood (Hulteen et al., 2018; Vallence et al., 2019). The physical changes associated with aging (Brook et al., 2016) explain the differences between young and older adults, both in process- and product-oriented outcomes (Williams et al., 1990, 1991, 1998). However, the proportion of mastery level is still higher in older adults than children, most likely due to the lifelong physical activity experience. The low proportion of mastery level in children is noticeable in that, according to Halverson et al. (1982), a larger proportion of children should have an advanced pattern of movement for OCS at a younger age. These relatively poor results are

Table 6. Percentage of participants demonstrating each movement component of kicking for accuracy and force, and mastery level by age group.

Component	Level	Children 1st grade [%]	Children 2nd grade [%]	Children 3rd grade [%]	Children 4th grade [%]	Children total [%]	Young adults [%]	Older adults [%]	statistical analysis*
Approach—support leg position in relation to the ball	SLP 1	58.3	70.6	46.7	54.5	57.7	0.0	15.0	χ^2 (10) = 66.9, p < .001
	SLP 2	33.3	29.4	46.7	40.9	37.2	27.3	70.0	
	SLP 3	8.3	0.0	6.7	4.5	5.1	72.7	15.0	
Backswing of the kicking leg (thigh)	BST 1	4.2	0.0	0.0	0.0	1.3	0.0	0.0	χ^2 (10) = 20.5, p = .025
	BST 2	41.7	35.3	20.0	9.1	26.9	13.6	55.0	
	BST 3	54.2	64.7	80.0	90.9	71.8	86.4	45.0	
Backswing of the kicking leg (lower leg)	BSL 1	29.2	23.5	0.0	4.5	15.4	13.6	60.0	χ^2 (10) = 40.9, p < .001
	BSL 2	29.2	5.9	20.0	9.1	16.7	4.5	25.0	
	BSL 3	41.7	70.6	80.0	86.4	67.9	81.8	15.0	
Ball contact	BC 1	29.2	41.2	33.3	22.7	30.8	0.0	5.0	χ^2 (10) = 26.5, p = .003
	BC 2	58.3	41.2	33.3	27.3	41.0	40.9	60.0	
	BC 3	12.5	17.6	33.3	50.0	28.2	59.1	35.0	
Upper trunk position during contact	TP 1	37.5	64.7	60.0	50.0	51.3	9.1	15.0	χ^2 (15) = 65.7, p < .001
	TP 2	4.2	0.0	0.0	4.5	2.6	59.1	55.0	
	TP 3	29.2	29.4	20.0	40.9	30.8	27.3	30.0	
	TP 4	29.2	5.9	20.0	4.5	15.4	4.5	0.0	
Arm action	A 1	37.5	17.6	6.7	22.7	23.1	4.5	15.0	χ^2 (15) = 47.8, p < .001
	A 2	33.3	58.8	86.7	77.3	61.5	27.3	60.0	
	A 3	29.2	23.5	6.7	0.0	15.4	54.5	25.0	
	A 4	0.0	0.0	0.0	0.0	0.0	13.6	0.0	
Mastery level		0.0	0.0	0.0	0.0	0	18.2	0.0	χ^2 (10) = 44.3, p < .001
masteryadvanced skill proficiency		8.3	0.0	6.7	9.1	6.4	45.5	10.0	
non-mastery		91.7	100.0	93.3	90.9	93.6	36.4	90.0	

*Chi-square test with children separated by grade.

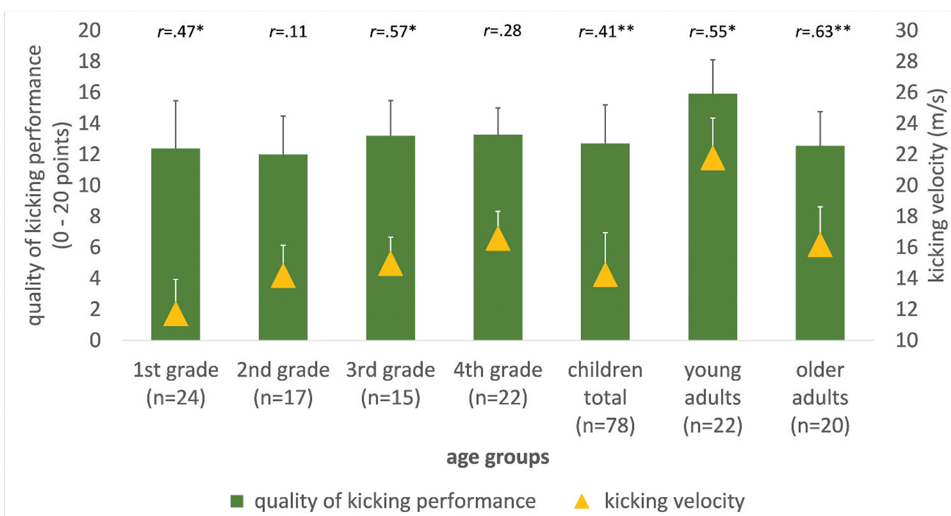

Figure 2. Means and standard deviations for process- and product-oriented kicking performance by age; correlation between process- and product-oriented measures by age group controlled for height and weight (* p < .05; ** p < .01).

not encouraging, considering the knowledge of the association between motor performance and lifelong physical activity (Duncan et al., 2019; Hulteen et al., 2018).

Product-oriented assessments

Regarding the product-oriented results, especially throwing and kicking velocities, there are significant differences between the age groups, with the highest velocities in the group of young adults, which is in line with the findings of Lorson et al. (2013). The results are therefore in line with our expectations since the throwing and kicking velocities are strongly dependent on the maximum and explosive strength, body composition (e.g., body size and fat-free mass), and technical aspects (Rodríguez-Lorenzo et al., 2016; Stodden et al., 2006a, 2006b; Van den Tillaar & Ettema, 2004). From muscle physiology, we know that strength increases from childhood to adulthood and decreases again from around 50 years of age (Brook et al., 2016), which is also reflected in our data.

In summary, the process-oriented and product-oriented results are in line with the results of Lorson et al. (2013), and thus our data provide support for a hypothetical lifespan developmental trajectory. No regression is observed in the group of older adults for catching. A meaningful comparison of throwing and kicking velocities with those of other studies is only insufficiently possible because athletes were often explicitly examined or other throwing objects were used (e.g., tennis balls; Lorson et al., 2013; Roberton & Konczak, 2001). Different object weights and sizes lead to different movement patterns (López-Moliner & Keil, 2012).

Table 7. Percentage of participants demonstrating each movement component of catching, and mastery level by age group.

Component	Level	Children 1st grade [%]	Children 2nd grade [%]	Children 3rd grade [%]	Children 4th grade [%]	Children total [%]	Young adults [%]	Older adults [%]	statistical analysis*
Arm action	AA 1	16.7	5.9	0.0	0.0	6.4	0.0	0.0	χ^2 (15) = 60.1,
	AA 2	8.3	11.8	0.0	0.0	5.1	0.0	5.0	$p < .001$
	AA 3	54.2	70.6	53.3	54.5	57.7	0.0	15.0	
	AA4	20.8	11.8	46.7	45.5	30.8	100.0	80.0	
Hand action	HA 1	41.7	29.4	26.7	27.3	32.1	0.0	0.0	χ^2 (410) = 46.9,
	HA 2	33.3	35.3	33.3	9.1	26.9	0.0	5.0	$p < .001$
	HA 3	25.0	35.3	40.0	63.6	41.0	100.0	95.0	
Body action	BA 1	4.2	0.0	0.0	0.0	1.3	0.0	0.0	χ^2 (4) = 51.0,
	BA 2	79.2	88.2	66.7	45.5	69.2	0.0	5.0	$p < .001$
	BA 3	16.7	11.8	33.3	54.5	29.5	100.0	95.0	
Mastery level		4.2	11.8	20.0	27.3	15.4	100.0	80.0	χ^2 (10) = 79.5,
masteryadvanced skill proficiency		20.8	0.0	13.3	27.3	16.7	0.0	15.0	$p < .001$
non-mastery		75.0	88.2	66.7	45.5	67.9	0.0	5.0	

*Chi-square test with children separated by grade.

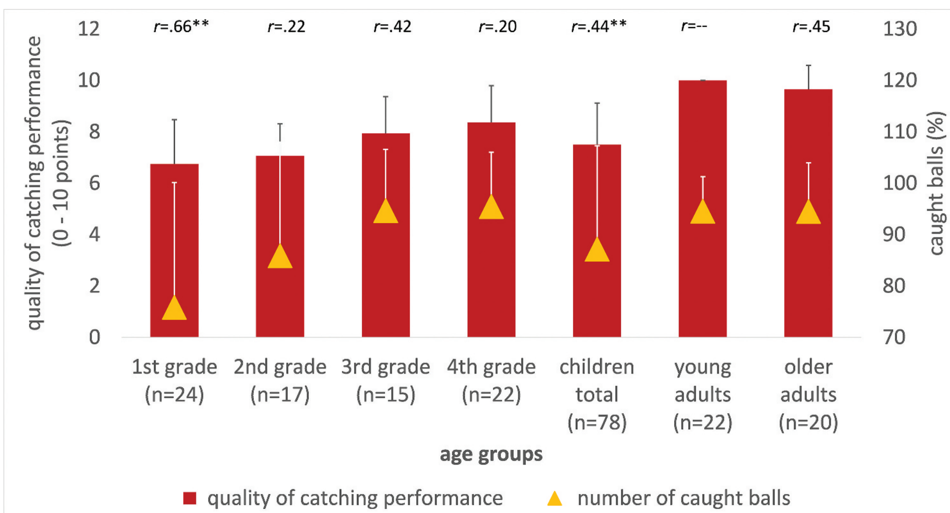

Figure 3. Means and standard deviations for process- and product-oriented catching performance by age; correlation between process- and product-oriented measures by age group controlled for height and weight (* $p < .05$; ** $p < .01$).

Relationships between process- and product-oriented assessments

Concerning the relationships between process- and product-oriented results for the three motor skills catching, throwing, and kicking (see Figures 1–3), predominantly moderate to large correlations were found for all age groups after controlling for height and weight, which correspond to correlations reported of True et al. (2017) and Logan et al. (2017). Regarding the studies of Roberton and Konczak (2001) and Stodden et al. (2006a, 2006b), component levels could explain 69% and more of the variance of throwing velocity; therefore, higher correlations were expected in the group of children. From a methodological point of view, it should be mentioned that Stodden et al. (2006a, 2006b) used markers and biomechanical 3D software for their movement analysis, which is more accurate than our subjective component approach. This methodological aspect may explain some of the low correlations (e.g., throwing: r = .10 for the 20–30 years old adults; kicking r = .27 for the 2nd graders).

In summary, the process- and product-oriented results of throwing and kicking show a similar trajectory over the life-span with a progression from childhood to young adulthood and regression in older adults. However, this is not the case for catching in the sense of relatively stable results in older adults.

It is important to note that this study is not without limitations. First, a larger sample would have been desirable to increase the statistical power and thus the significance of our results. A longitudinal design instead of the cross-sectional would also increase the informative value, allowing the analysis of developmental trajectories within OCS of both process- and product-oriented results. Furthermore, we did not consider middle-aged adults to reflect the link between function and the decline of function from young adulthood to older adulthood. In addition, no girls and women were included so that no statements can be made about a possible gender gap which would have been particularly interesting for kicking in the male-dominated sports soccer. Finally, although it is a common practice, the subjective assessment of two raters contributes to the fact that study results cannot be optimally compared with other studies. Therefore, sensor systems for easier identification of nodal points of motor skills seem to be an important methodical aspect for improving data quality and less time-consuming procedure in the research of motor development.

What does this article add?

As far as we know, the present study is the first to examine process- and product-oriented aspects of catching, throwing, and kicking in three different male age groups representing the life span. This not only supports the results of Lorson et al. (2013) for a hypothetical lifespan developmental trajectory for throwing, but it also extends it to younger and older age groups with two additional motor skills. The data on throwing and kicking demonstrated similar results for the 8 to 10-years old boys and the 60+ years old men, which is not the case for catching, presumably due to the different requirements for explosive strength and visual-motor integration. This assumption should be investigated in future studies.

Acknowledgments

The authors would like to thank Patrick Schütze for their valuable assistance in the data collection process. Also, the authors wish to thank the school and all the children, adults, and older adults for participating in this study.

Ethics

Informed written consent was obtained prior to the beginning of testing. In the case of children (<18 yrs), additional informed written consent was also provided from their parent or guardian. Participants were told that they could opt out at any time. All procedures were in accordance to the Declaration of Helsinki (2013) with ethical standards, legal requirements and international norms. The institutional ethics committee approved the project.

Funding

The work was not supported by any funding agencies.

References

Bloomfield, J., Elliott, B., & Davies, S. (1979). Development of the soccer kick: A cinematographical analysis. *Journal of Human Movement Studies*, *5*, 152–159.

Brook, M. S., Wilkinson, D. J., Phillips, B. E., Perez-Schindler, J., Philp, A., Smith, K., & Atherton, P. J. (2016). Skeletal muscle homeostasis and plasticity in youth and ageing: Impact of nutrition and exercise. *Acta Physiologica*, *216*(1), 15–41. https://doi.org/10.1111/apha.12532

Burton, A. W., & Rodgerson, R. W. (2003). The development of throwing behavior. In G. Savelsbergh, K. Davids, J. Van der Kamp, & S. Bennett (Eds.), *Development of movement coordination in children: Applications in the field of ergonomics, health sciences and sport* (pp. 225–240). Routledge.

Clark, J. E., & Metcalf, J. S. (2002). The mountain of motor development: A metaphor. In J. E. Clark & J. H. Humphrey (Eds.), *Motor development: Reserch and reviews* (Vol. 2, pp. 163–190). National Association for Sport and Physical Education.

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155

Duncan, M. J., Roscoe, C. M., Noon, M., Clark, C. C., O'Brien, W., & Eyre, E. L. (2019, December). 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), 293–310. https://doi.org/10.1177/1356336X19888953

Gromeier, M., Koester, D., & Schack, T. (2017). Gender differences in motor skills of the overarm throw. *Frontiers in Psychology*, *8*, 212. https://doi.org/10.3389/fpsyg.2017.00212

Halverson, L. E., Roberton, M. A., & Langendorfer, S. (1982). Development of the overarm throw: Movement and ball velocity changes by seventh grade. *Research Quarterly Exercise Sport*, *53*(3), 198–205. https://doi.org/10.1080/02701367.1982.10609340

Haubenstricker, J., Branta, C., & Seefeldt, V. (1983). *Preliminary validation of developmental sequences for throwing and catching* [Paper presented]. Annual conference of the North American Society for the Psychology of Sport and Physical Activity, East Lansing, MI.

Haywood, K., & Getchell, N. (2014). *Life span motor development* (6th ed.). Human Kinetics.

Haywood, K., Roberton, M. A., & Getchell, N. (2012). *Advanced analysis of motor development*. Human Kinetics.

Herold, F., Hamacher, D., Schega, L., & Müller, N. G. (2018). Thinking while moving or moving while thinking - concepts of motor-cognitive training for cognitive performance enhancement. *Frontiers in Aging Neuroscience*, *10*(Article), 228. https://doi.org/10.3389/fnagi.2018.00228

Holfelder, B., Stierle, P., Hohmann, T., & Schott, N. (2013). *Der Schuss im Fussball: Eine qualitative und quantitative Analyse*. Sportmotorik-Tagung der Deutschen Vereinigung fuer Sportwissenschaft.

Hulteen, R. M., Morgan, P. J., Barnett, L. M., Stodden, D. F., & Lubans, D. R. (2018). Development of foundational movement skills: A conceptual model for physical activity across the lifespan. *Sports Medicine*, *48*(7), 1533–1540. https://doi.org/10.1007/s40279-018-0892-6

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Langendorfer, S. J., & Roberton, M. A. (2002). Individual pathways in the development of forceful throwing. *Research Quarterly for Exercise & Sport*, *73*(3), 245–256. https://doi.org/10.1080/02701367.2002.10609018

Logan, S. W., Barnett, L. M., Goodway, J. D., & Stodden, D. F. (2017). Comparison of performance on process- and product-oriented assessments of fundamental motor skills across childhood. *Journal of Sports Sciences*, *35*(7), 634–641. https://doi.org/10.1080/02640414.2016.1183803

López-Moliner, J., & Keil, M. S. (2012). People favour imperfect catching by assuming a stable world. *PLoS One*, *7*(4), e35705. https://doi.org/10.1371/journal.pone.0035705

Lorson, K. M., Stodden, D. F., Langendorfer, S. J., & Goodway, J. D. (2013). Age and gender differences in adolescent and adult overarm throwing. *Research Quarterly for Exercise & Sport*, *84*(2), 239–244. https://doi.org/10.1080/02701367.2013.784841

Mally, K. K., Battista, R. A., & Roberton, M. A. (2011). Distance as a control parameter for place kicking. *Journal of Human Sport and Exercise*, *6*(1), 122–134. https://doi.org/10.4100/jhse.2011.61.14

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

Roberton, M. A., & Konczak, J. (2001). Predicting children's overarm throw ball velocities from their developmental levels in throwing. *Research Quarterly Exercise Sport*, *72*(2), 91–103. https://doi.org/10.1080/02701367.2001.10608939

Rodríguez-Lorenzo, L., Fernandez-del-olmo, M., & Martín-Acero, R. (2016). Strength and kicking performance in soccer. A review. *Strength and Conditioning Journal*, *38*(3), 106–116. https://doi.org/10.1519/SSC.0000000000000223

Schott, N., & Klotzbier, T. (2018). The motor-cognitive connection: Indicator of future developmental success in children and adolescents?! In R. P. Bailey, R. Meeusen, S. Schäfer-Cerasari, & P. Tomporowski (Eds.), *Physical activity and educational achievement: Insights from exercise neuroscience* (pp. 111–129). Routledge.

Schott, N., & Munzert, J. (2010). *Motorische Entwicklung*. Hogrefe.

Scott, M. A., Williams, A. M., & Horn, R. R. (2003). The coordination of kicking techniques in children. In G. Savelsbergh, K. Davids, J. Van der Kamp, & S. Bennett (Eds.), *Development of movement coordination in children: Applications in the field of ergonomics, health sciences and sport* (pp. 241–250). Routledge.

Stodden, D. F., Langendorfer, S. J., Fleisig, G. S., & Andrews, J. R. (2006a). Kinematic constraints associated with the acquisition of overarm throwing part I: Step and trunk actions. *Research Quarterly for Exercise and Sport*, *77*(4), 417–427. https://doi.org/10.1080/02701367.2006.10599377

Stodden, D. F., Langendorfer, S. J., Fleisig, G. S., & Andrews, J. R. (2006b). Kinematic constraints associated with the acquisition of overarm throwing part II: Upper extremity actions. *Research Quarterly for Exercise and Sport*, *77*(4), 428–436. https://doi.org/10.1080/02701367.2006.10599378

Strohmeyer, H. S., Williams, K., & Schaub-George, D. (1991). Developmental sequences for catching a small ball: A prelongitudinal screening. *Research Quarterly for Exercise & Sport*, *62*(3), 257–266. https://doi.org/10.1080/02701367.1991.10608722

True, L., Brian, A., Goodway, J., & Stodden, D. (2017). Relationships between product- and process-oriented measures of motor competence and perceived competence. *Journal of Motor Learning and Development*, *5*(2), 319–335. https://doi.org/10.1123/jmld.2016-0042

Vallence, A. M., Hebert, J., Jespersen, E., Klakk, H., Rexen, C., & Wedderkopp, N. (2019). Childhood motor performance is increased by participation in organized sport: The CHAMPS Study-DK. *Scientific Reports*, *12*(9), 18920. https://doi.org/10.1038/s41598-019-54879-4

Van den Tillaar, R., & Ettema, G. (2004). Effect of body size and gender in overarm throwing performance. *European Journal of Applied Physiology*, *91*(4), 413–418. https://doi.org/10.1007/s00421-003-1019-8

Vieira, L. H. P., Cunha, S. A., Moraes, R., Barbieri, F. A., Aquino, R., Oliveira, L. D. P., Navarro, M., Bedo, B. L. S., & Santiago, P. R. P. (2018). Kicking performance in young U9 to U20 soccer players: Assessment of velocity and accuracy simultaneously. *Research Quarterly for Exercise and Sport*, *89*(2), 210–220. https://doi.org/10.1080/02701367.2018.1439569

Weisberg, A., Le Gall, J., Stergiou, P., & Katz, L. (2020). Comparison of two methods to estimate the maximal velocity of a ball during an overhand throw. *Proceedings*, *49*(43), 1–6. https://doi.org/10.3390/proceedings2020049043

Williams, K., Haywood, K., & VanSant, A. (1990). Movement characteristics of older adult throwers. In J. Clark & J. Humphrey (Eds.), *Advances in motor development research* (Vol. 3, pp. 29–44). AMS Press.

Williams, K., Haywood, K., & VanSant, A. (1991). Throwing patterns of older adults: A follow-up investigation. *The International Journal of Aging and Human Development*, *33*(4), 279–294. https://doi.org/10.2190/891H-V1M1-493B-GP4P

Williams, K., Haywood, K., & VanSant, A. (1998). Changes in throwing by older adults: A longitudinal investigation. *Research Quarterly for Exercise & Sport*, *69*(1), 1–10. https://doi.org/10.1080/02701367.1998.10607661