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Neurocognitive Performance, Vestibulo-Ocular Function and Postural Control in Youth Male Soccer and Basketball Players of Different Ages

Neurokognitive Leistung, vestibulo-okuläre Funktion und posturale Kontrolle jugendlicher männlicher Fußball- und Basketballspieler verschiedener Altersklassen

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Summary

› **Purpose:** Neurocognitive, vestibulo-ocular, and balance assessments can assist in screening and management of potential sports-related concussions. This cross-sectional study aimed to examine the effect of age on neurocognitive performance, vestibulo-ocular function, dynamic visual acuity, and postural control in high-level adolescent ball sport athletes.

› **Methods:** In 139 male adolescent soccer and basketball players (under-11, under-15, under-19) assessments of neurocognitive performance (CNS Vital Signs), vestibulo-ocular reflex (video head impulse test), dynamic visual acuity (dynamic visual acuity test), and postural control (stability evaluation test) were performed. ANOVA and Kruskal-Wallis tests (post-hoc Bonferroni correction) were used for comparisons between age groups.

› **Results:** Neurocognitive functioning (composite memory, psychomotor speed, reaction time, complex attention, cognitive flexibility, processing speed; $p<0.008$, $\eta^2=0.24$ to 0.71), vestibulo-ocular reflex gain ($p=0.018$, $\eta^2=0.06$), dynamic visual acuity loss ($p<0.001$, $\eta^2=0.11$), and sway velocity ($p<0.001$, $\eta^2=0.36$) differed significantly between age groups. Medium to large effects, with better performance in older compared to under-11 males, were found.

› **Conclusion:** Under-11 male athletes revealed considerably lower neurocognitive, vestibulo-ocular reflex, dynamic visual acuity, and postural control performance compared to older youth athletes. Hence, this age group should be tested in smaller intervals to assess age-adequate performance and post-injury impairment. Further longitudinal studies may aid in the development of normative vestibulo-ocular reflex gain, dynamic visual acuity, and sway velocity values for ball sports.

KEY WORDS:
Baseline, Neuropsychological Test, Visual Acuity, Vestibular System

Introduction

Sports-related concussions (SRC; the mildest form of mild traumatic brain injury (mTBI)) most frequently occur in contact and collision sports and result in a range of clinical signs and symptoms (23). A multimodal assessment is recommended in the diagnosis and management of SRC, including investigations of neurocognition, vestibulo-ocular reflex (VOR), oculomotor function, and balance (5, 23). Objective tools such as the standardized computerized neurocognitive exam tools, video head impulse test (vHIT), assessment of dynamic visual acuity (DVA), and postural sway via force plate are already used in the clinic and research on mTBI (3, 11, 18). Individual pre-injury baseline data or an adequate norm sample greatly facilitate the interpretation of data obtained after SRC. While using norm values seems to have a high specificity regarding cognitive impairments and is sometimes more feasible, baseline data are considered to be more sensitive in neurocognitive testing (4, 17).

In ball sports such as soccer and basketball, a large proportion of players are adolescents (6), a period in which the brain, particularly executive functions, and body develop (13). Neurocognitive performance has been shown to develop noticeably each year in high-school athletes between the ages of about 14 to 18, whereas younger ages have not been examined (27). While there seems to be no difference between age groups in the VOR of young soccer players (30), single studies found age-related changes in DVA (16). Postural stability was found to improve with age in youth (28), while balance did not depend on age in adolescent and adult soccer players (30). Studies investigating vestibular function in youth athletes are rare (22, 30). Therefore, the influences of age on performance in computerized neurocognitive, vestibulo-ocular, and postural control assessments in adolescent athletes, particularly of young age, remain to be elucidated, to identify optimal intervals to repeat baseline examinations. Also, age-appropriate norm values for youth ball sport players need to be investigated.

This cross-sectional study aimed to examine the effect of age on neurocognitive performance, VOR, DVA, and postural control in high-level adolescent ball sport players. We hypothesized to find signifi-

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Table 1

Description of test battery to assess neurocognitive, vestibulo-ocular, and postural control performance with parameters used for analysis. DVA=dynamic visual acuity; VOR=vestibulo-ocular reflex.

TEST	DESCRIPTION OF ASSESSMENT	PARAMETER
CNS Vital Signs	To assess neurocognitive performance, 7 established neuropsychological tests (Verbal Memory, Visual Memory, Finger Tapping, Symbol Digit Coding, Stroop Test, Shifting Attention, and Continuous Performance) were performed in the athlete's native language from which 11 domain scores were generated and 6 used for analyses.	Domain scores: composite memory, psychomotor speed, reaction time, complex attention, cognitive flexibility, processing speed
Video head impulse test	VOR in all six semicircular canals was investigated while the participant wore monocular goggles with an infrared camera recording the right eye. The height of the fixation dot on the wall was 120 cm, with 1-meter distance between the participant and the wall. The athlete's head was rapidly and unpredictably turned at changing directions with amplitudes of 10-20 deg and at peak head velocities between 120-250 (lateral) and 100-250 (vertical) deg/s. A minimum of 20 (lateral) and 10 (vertical) correct impulses to each direction, with minimum frame rates of 220 frames/s, were needed for test completion.	Total, lateral, anterior, and posterior VOR-gain (eye movement velocity / head movement velocity)
Dynamic visual acuity test	After the assessment of static visual acuity and perception time, lateral DVA was measured. Perception time should be <60 ms to guarantee valid results. Head movement velocity should be between 85-120 deg/s with an amplitude of around 20 deg in each direction. The distance between display and participant was three meters.	Lateral loss between static and dynamic visual acuity (DVA loss; in logMAR)
Stability evaluation test	Balance performance was measured in three different stances on a static force plate: double-leg, single-leg, and tandem stance, each on a firm and foam surface. The participant was asked to stand as motionless as possible, with eyes closed and hands in hips for 20 seconds in each condition.	Sway velocity (in deg/s) of all six stances

Table 2

Characteristics of ball sport athletes with mean age, height, body mass index, career length in sports, migraine, and concussion prevalence. BMI=body mass index.

	UNDER-11 MALE	UNDER-15 MALE	UNDER-19 MALE	TOTAL
n (% soccer)	45 (64.4)	43 (67.4)	51 (74.5)	139 (69.1)
Age, years (SD)	10.4 (0.6)	14.5 (0.6)	17.8 (0.7)	14.4 (3.1)
Height, cm (SD)	145.3 (8.8)	176.6 (11.5)	184.7 (9.4)	169.7 (19.7)
BMI (SD)	16.7 (1.5)	19.6 (1.7)	22.4 (1.3)	19.8 (2.8)
Career length, years (SD)	5.0 (1.8)	7.9 (2.1)	11.3 (2.8)	8.3 (3.5)
Education, n (%)				
primary school	13 (28.9)	0 (0)	0 (0)	13 (9.4)
high school	32 (71.1)	42 (97.7)	30 (58.8)	104 (74.8)
graduated	0 (0)	0 (0)	15 (29.4)	15 (10.8)
no information	0 (0)	1 (2.3)	6 (11.8)	7 (5.0)
Migraine, n (%)	1 (2.2)	1 (2.3)	6 (11.8)	8 (5.8)
12-month concussion prevalence, n (%)	0 (0)	2 (4.7)	2 (3.9)	4 (2.9)
Lifetime concussion prevalence, n (%)	2 (4.4)	6 (14.0)	14 (27.5)	22 (15.8)

cantly better neurocognitive, VOR, DVA, and balance performance with increasing age. Performance assessed by standardized computerized testing, vHIT, DVA test, and stability evaluation test (SET) were investigated regarding sports-specific differences within a pilot study, as baseline values may depend on sports-specific risk profiles aside from concussion (e.g. heading in soccer).

Methods

At the beginning of the seasons 2019/20 and 2020/21, players from high-level male under-11 (U11), under-15 (U15), and under-19 (U19) youth soccer and basketball teams were evaluated for neurocognitive, VOR, and postural control parameters. All players were approached via personal contact with club officials and coaches. Every athlete and their guardian (if <18 years) provided written informed consent before participation. The study was approved by the ethics committee of the Ärztekammer Westfalen-Lippe in Münster, Germany (2019-321-f-S) and registered at DRKS (DRKS00018923).

The inclusion criteria were regularly participating in official matches in one of the top three leagues of their age group and completion of minimum one test presented below. Exclusion criteria were head injuries, lower extremity injuries for testing postural control, or medication intake influencing the visual or vestibular system at the day of testing.

The study protocol included a collection of demographics, information on sports, medical, and head injury history via questionnaire, in addition to pre-season baseline tests (table 1). Neurocognitive performance was evaluated through a computerized assessment using CNS Vital Signs (Morrisville, NC, USA) (10). Six domain scores were used for analysis (24). Invalid scores were excluded based on the validity indicator (9). The VOR was quantified via vHIT (ICS Impulse, Otometrics, Taastrup, Denmark) (19). The VOR-gain of all semicircular canals was analyzed. Values of <0.8 (lateral), <0.6 (vertical), and ›

Table 3

Neurocognitive domain, VOR-gain, DVA Loss, and sway velocity scores for athletes of different age groups. SD=standard deviation; [a]=lower scores indicate better performance; VOR=vestibulo-ocular reflex; Effect sizes η^2 of 0.01, 0.06, and 0.14 correspond to small, medium, and large effects, respectively (2). **=p value <=0.001; *=Bonferroni corrected p value <0.017 in VOR-gain.

	UNDER-11 (N=45)		UNDER-15 (N=43)		UNDER-19 (N=51)		η^2
	MEAN	SD	MEAN	SD	MEAN	SD	
Neurocognitive function (n=139)							
Composite memory	93.90	8.50	99.90	7.40	98.80	6.10	0.113**
Psychomotor speed	137.50	17.00	177.70	24.10	192.80	21.70	0.586**
Reaction time[a]	838.70	92.50	649.30	96.20	608.00	72.10	0.574**
Complex attention[a]	23.00	10.90	17.50	13.10	11.30	6.30	0.256**
Cognitive flexibility	19.70	12.60	34.00	15.60	44.30	11.00	0.415**
Processing speed	35.80	7.80	53.00	11.30	59.00	10.60	0.429**
Executive function	22.90	11.50	36.80	15.20	46.50	10.80	
Simple attention	35.80	4.90	38.60	2.00	39.00	1.20	
Motor speed	100.00	14.30	122.40	18.40	132.50	15.80	
VOR-gain (n=136)							
Total	0.93	0.07	0.97	0.06	0.95	0.06	0.058*
Lateral							0.011
left	0.95	0.09	0.97	0.09	0.95	0.06	
right	1	0.07	1.02	0.07	1.02	0.06	
Anterior							0.025
left	0.84	0.13	0.9	0.09	0.89	0.08	
right	0.9	0.15	0.98	0.1	0.97	0.11	
Posterior							0.078*
left	0.91	0.12	0.97	0.1	0.94	0.11	
right	0.9	0.12	0.96	0.1	0.91	0.08	
DVA Loss (n=136)							
Lateral	0.22	0.08	0.17	0.09	0.16	0.08	0.110**
left	0.22	0.09	0.16	0.1	0.17	0.1	
right	0.22	0.11	0.17	0.11	0.15	0.09	
Sway velocity (n=139)							
Total	3.42	0.81	2.37	0.63	2.25	0.53	0.358**
double firm	0.98	0.26	0.72	0.18	0.69	0.2	0.252**
single firm	3.1	1.07	2.12	0.69	1.91	0.61	0.275**
tandem firm	2.54	1.18	1.73	1.04	1.4	0.6	0.297**
double foam	2.52	0.63	2.22	0.54	2.04	0.44	0.107**
single foam	5.66	1.83	3.72	1.1	3.7	1.15	0.287**
tandem foam	5.71	2.25	3.71	1.62	3.74	1.54	0.158**

>1.2 were counted as invalid (8). The DVA test (NeuroCom In-Vision, Natus Medical Incorporated, Seattle, USA) was implemented to measure DVA loss. Postural control was assessed via SET (NeuroCom VSR, Natus Medical Incorporated, Seattle, USA) to analyze sway velocity. Tests were carried out in successive stations.

Sample size calculation was based on an a priori power analysis (G*Power, v.3.1.9.4) using literature, which showed neurocognitive performance differences between 10 to 18-year-old athletes, for example in reaction time (η^2=0.22) (7). A minimum of 38 athletes in total were required to reach statistical power of 80% (η=0.05) for investigating age group differences. Statistical analysis was performed using SPSS 29 (IBM). Descriptive statistics are presented as the mean with standard deviation (SD) and frequencies with percentages. Parameters were checked for normal distribution by the Shapiro-Wilk test. To exclude effects of sports, comparisons in test scores between soccer and basketball players of the same age using t test or Mann-Whitney-U test and logistic regression models, adjusting for potential effects of career length, concussion history, migraine, and height, were conducted. ANOVA or Kruskal-Wallis test was used to compare parameters between age groups. If homogeneity of variance, tested using Levene's test, was violated in normally distributed data WELCH-ANOVA with Games-Howell post hoc analysis was used. Otherwise, post hoc tests with Bonferroni correction for multiple comparisons were conducted. The level of significance for statistical tests was defined as p<0.05 (Bonferroni corrected in neurocognitive domains: p=0.008). Effect sizes were expressed as eta-square with 0.01, 0.06, and 0.14 and Cohen's d with 0.2, 0.5, and 0.8 corresponding to small, medium, and large effects, respectively (2).

Results

In total, 139 athletes were enrolled in the study (table 2). No participant reported diagnosed ADHD, learning/mental disorders, or medication intake leading to exclusion.

There were no significant differences between soccer and basketball players of the same age in neurocognitive functions (composite memory: d=0.03 to 0.18; other domains: η^2=0.00 to 0.04), VOR-gain (d=0.11 to 0.63), DVA loss (d=0.01 to 0.52), and sway velocity (all p>0.05, η^2=0.00 to 0.06), also after adjusting for effects of confounders (see supplementary tables 4 and 5 online).

Age group differences and scores of neurocognitive domains, VOR-gain, DVA loss, and sway velocity for all ages are presented in table 3. Neurocognitive functioning differed significantly between age groups, showing large effects. Composite memory (U11 vs. U15: p<0.001, U11 vs. U19: p=0.005, d=0.67 to 0.75), psychomotor speed, reaction time, cognitive flexibility, and processing speed were significantly worse in U11 than in all older ages (p<0.001, η^2=0.24 to 0.71). Complex attention was worse in U11 compared to U19 (p=0.000, η^2=0.39). Cognitive flexibility differed significantly between U15 and U19 players (p=0.003, η^2=0.14).

The total VOR-gain differed significantly between teams (F (2, 133)=4.125, p=0.018), with lower scores in U11 than in U15 players (p=0.015, d=0.58). Considering the semicircular canals, the same medium effect was significant only for the average posterior gain (F (2, 134)=5.662, p=0.004, d=0.64).

Lateral DVA loss was significantly different between age groups (F (2,133)=8.204, p<0.001, η^2=0.11). U11 males showed significantly higher means than U15 (p=0.004, d=0.68) and U19 (p<0.001, d=0.8) males.

Total sway velocity differed between age groups (Chi^2 (2)=50.699, p<0.001, η^2=0.36). U11 did show significantly higher values than U15 and U19 males (p=0.000, η^2=0.36 to 0.46). These differences were observed for all stances, with large effects (p<0.001, η^2=0.16 to 0.38). No further differences were displayed.

Discussion

In this cross-sectional study, effects of age on neurocognitive performance, VOR, DVA, and postural control were investigated in high-level adolescent soccer and basketball players. Neurocognitive functioning, VOR-gain, DVA loss, and sway velocity differed significantly between youth age groups, with boys U11 revealing lower performance compared to older players. Scores of neurocognitive domains, VOR-gain, DVA loss, and sway velocity are presented as a step towards developing norm values for youth athletes of different ages playing soccer and basketball.

Neuropsychological, vestibulo-ocular, and balance assessments can assist in SRC screening and management (5). As these functions develop with age in adolescents, large intervals between baseline examinations may lead to inadequate performance representation and thus to difficulties in the interpretation of post-injury performance (13, 28). In all neurocognitive domains, significantly better performance with medium to large effects was observed in older compared to U11 male players in our study. These results confirm previous reports, where athletes aged 10 to 12 years performed worse than those aged 13 to 15 years, and 16 to 18 years on computerized neurocognitive testing (7). In another study, substantial improvement with age in 10-year-old adolescents over a two-year follow-up was found (1). Cross-sectional analyses of more than 3000 high school athletes demonstrated better neurocognitive performance each year of age in all domains except for verbal and visual memory (27). In the present study, moderate to large significant differences in cognitive flexibility and better performance in all domains but memory were found between U15 and U19 males, confirming previous findings.

The average VOR-gain was significantly higher in U15 than in U11 players. These results are partly in line with results from Tarnutzer et al., as they found main effects for age and lower VOR-gains in <18-year-old high-level athletes compared to older ages (30). Taking the semicircular canals into account, age-related differences were found only for the posterior semicircular canals in this study, supporting an impact of age described for the vertical semicircular canals in ice-hockey players (30). In high-level soccer players aged 13-39 years, no age-related changes were found in previous literature (30). This could be in contrast to our results, while the younger age of players in our study seems crucial. As no further differences between U19 and younger groups appeared, the findings extend the results of previous studies showing no age-dependency of VOR-gain in adolescents (20).

Lateral DVA loss was significantly better in U15 and U19 than in U11 players, with moderate to large effects. Similar to the presented results, Ishigaki et al. found a rapid development in DVA between the ages of 5 and 15 years in a fixed head and moving optotype testing situation (12). Further studies corroborated age-related effects on DVA (16), whereas no age group differences were found in other studies (16, 26). The DVA in adolescents has rarely been investigated in previous studies and the use of different testing paradigms complicates comparisons to our results. Therefore, the presented data add valuable information regarding the application of DVA baseline testing in adolescent ball sport athletes. Sports participation might also have influenced the results, as U19 players had a mean career duration of 11 years compared to 5 years in U11 (14).

A review on age-related differences in balance concluded considerable disagreement on the (non-)linearity of postural sway development in children (31). The present study revealed large age-related differences in sway velocity between U11 and older athletes, with better performance in older players. This confirms data presented in a review and meta-analysis by Schedler et al. (28). They found better balance performances in adolescents compared to children, indicating that maturation of postural control possibly is not completed in childhood, where sensory integration improves and postural control strategies change (28, 29). Increased muscle strength and better attentional capabilities by age might also justify age group differences (28). Another study on young athletes additionally showed that postural stability scores significantly improved between 9 and 13 years of age (22).

Between soccer and basketball players, no differences in pre-season testing were found, which is in line with the literature (7, 21, 25). Further ball sports should be included in future studies for better evidence regarding sports-specific effects.

For an adequate post-injury interpretation, the described developmental neurocognitive, vestibulo-ocular, and balance changes between ages 10 and 14 indicate the necessity for repeated baseline testing in this age range. Differences between 14 and 18-year-old ball sport players seem less significant, while optimal intervals for collecting baseline values in adolescence need to be further evaluated in future longitudinal studies. ›

Some methodological considerations need to be taken into account. The current study was a cross-sectional study. However, this approach is frequently used in literature (7, 30) and age groups were well comparable. Unfortunately, only male athletes were included, as female teams meeting the inclusion criteria with comparable age were not regionally available. To investigate influences of age, sex, and sports on neurocognitive domains, VOR, and postural control in female adolescent athletes, further research is needed. Four U19 players had already taken the test battery before study participation due to baseline or concussion assessment. In these individuals, influences of possible learning effects cannot be ruled out. The order of test administration within the assessment battery may influence performance across assessments (15). While the order of testing (e.g. CNS Vital Signs – DVA - SET – vHIT) was different between athletes, the proportional distribution of testing order was similar across groups, minimizing influences on results. While vHIT was applied by the same investigator, granting similar peak head velocities in all participants, neurocognitive, DVA, and postural control tests were conducted by different examiners. As CNS Vital Signs is a self-administered assessment, sway velocity was measured via force plate, and inter-rater reliability was previously described, no operator-dependent influences on test results are assumed (10, 26). In contrast to testing in the 2019/20 season, some athletes needed to wear masks during testing in 2020/21 season due to COVID-19-specific hygiene conditions. However, a standardized setting and operation procedure for the tests should have guaranteed valid, reliable measurements and should be adhered to in future studies. Cumulative overt catch-up saccades per trial, assessing VOR, were not analyzed, as they were shown to be below the cut-off for indicating peripheral-vestibular deficits in adolescent athletes (30).

Conclusions

U11 males revealed considerably lower neurocognitive, VOR, DVA, and postural control performance than older youth ball sport athletes. Individual reference values are needed for a sensitive detection of potential head injuries. When collecting baseline values, soccer and basketball players under the age of 11 should be tested in smaller intervals up to the age of 14, for age-adequate performance representations and post-injury interpretation. Analyses of exact time periods when changes might be most noticeable between ages 10 and 14 were not possible and optimal intervals for test administration need to be evaluated in future longitudinal studies. As a perspective, neurocognitive, VOR-gain, DVA loss, and sway velocity scores were presented as preliminary norm values for high-level male adolescent soccer and basketball athletes, while further studies are needed to replicate and extend particularly vestibulo-ocular, and balance scores. ■

Conflict of Interest
The authors have no conflict of interest.

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Ethical Approval
This study is approved by the Ethics Committee of the Ärztekammer Westfalen-Lippe in Münster, Germany (2019-321-f-S). Written and verbal consent was obtained directly from all participants, and from parents or guardians, if the participant was under the age of 18.

Summary Box

Under-11 males revealed considerably lower neurocognitive, vestibulo-ocular reflex, dynamic visual acuity, and postural control performance than older youth ball sport athletes.

When collecting individual baseline values, soccer and basketball players under the age of 11 should be tested in smaller intervals up to the age of 14, for age-adequate performance representations and interpretations post potential head injuries.

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