Intelligence 102 (2024) 101805

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

No spatial advantage in adolescent hockey players? Exploring measure specificity and masked effects

Ksenia Bartseva [a], Maxim Likhanov [a,c], Elina Tsigeman [a,b], Evgenia Alenina [a,b], Ivan Reznichenko [d], Elena Soldatova [a], Yulia Kovas [e,*]

[a] Department of Psychology, Saint Petersburg State University, Saint Petersburg, Russia
[b] Laboratory for Social and Cognitive Informatics, HSE University, Saint Petersburg, Russia
[c] State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, China
[d] Avangard Hockey Club Medical Center, Omsk, Russia
[e] Department of Psychology, Goldsmiths University of London, London, UK

ARTICLE INFO

Keywords:
Spatial ability
Spatial cognition
Ice hockey
Adolescent athletes
Academic achievement

ABSTRACT

The study examines how intensive hockey training is linked with spatial ability and academic performance. Participants were hockey players from top junior teams (N = 225, mean age = 14.25, all boys) and their unselected peers (N = 278, mean age = 15.47, all boys). Compared to the unselected group, hockey players showed lower results in 10 small-scale spatial tests (Cohen's d ranging from 0.42 to 1.04), Raven's Progressive Matrices (d = 0.41), and 12 school subjects (d for the sum of grades = 1.17). The differences in spatial ability remained significant after controlling for Raven's (d varying from 0.26 to 1.03). The absence of spatial advantage in athletes suggests that effects of sports on cognition are complex: spatial ability facet-specific, sport-specific, professional and intensity level-specific. Moreover, these effects might be confounded by differences in academic engagement, investment of effort and psychological and physiological effects of intensive sports engagement.

1. Introduction

Research has found positive associations between sport engagement and cognition (Ludyga, Gerber, Pühse, Looser, & Kamijo, 2020), including spatial ability (SA) - an ability to represent and process spatial information (Hegarty & Waller, 2005). For example, according to the meta-analysis by Voyer and Jansen (2017), athletes demonstrate on average higher SA compared with non-athletes (d = 0.38).

However, results showed that this link can be moderated by spatial measure, as different tests may tap into only partially overlapping spatial processes. The distinction between small and large scale SA is one of the existing models of spatial ability structure (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Jansen, 2009; Wang, Cohen, & Carr, 2014). The small-scale group includes SA components that are linked with mental operations with objects visualization, transformation, mental rotation and manipulation; while the large-scale SA includes processing of changes in the spectator's visual perspective and navigation (Hegarty, 2004). There is some evidence for a unifactorial structure of SA, with high commonalities across small-scale tasks (Budakova et al., 2021; Likhanov et al., 2018; Rimfeld et al., 2017) and strong correlations between small and large scales tasks (e.g. Malanchini et al., 2020). This overlap has been attributed to overlapping genetic factors (Malanchini et al., 2020). However, these common factors explained from around 30 to 55% of variance, suggesting a partial dissociation of underlying cognitive processes (Hegarty et al., 2006). One recent study applied a network analysis approach - Gaussian graphical models, to 10 small- and 6 large-scale tests and showed differential links across spatial facets when controlling for common variance (Likhanov et al., 2022). This finding suggests some etiological specificity of different facets of SA, which may explain the observed differences in the links between SA facets and sports. Indeed, the meta-analysis showed that the links between sports and different facets of SA differ in strength: mental rotation (d = 0.33); spatial perception (d = 1.09); and spatial visualization (d = 0.30) (Voyer & Jansen, 2017).

Results also showed that this effect can be moderated by sport type. Positive associations of SA and sport have been observed for many specific sports, including climbing (Pietsch & Jansen, 2018), sailing (Devlin, 2004), dancing (Jansen, Kellner, & Rieder, 2013), golf (Jansen, 2016) and basketball (Weigelt & Memmert, 2020). Although it is difficult to compare effects from individual studies, the aforementioned

* Corresponding author at: Department of Psychology, Goldsmiths University of London, New Cross, London SE14 6NW, UK.
E-mail address: y.kovas@gold.ac.uk (Y. Kovas).

https://doi.org/10.1016/j.intell.2023.101805
Received 29 August 2023; Accepted 9 December 2023
Available online 26 December 2023

meta-analysis suggested the largest effect size for combat sports (d = 0.91) compared with ball sports, running, dancing, and other sport activities. It has been suggested by the authors that these differences in effects might be a product of specifics of motor activity required for a particular sport. For example, one study showed that 10-month wrestling training showed a larger improvement in mental rotation performance than running (i.e. a sport that has presumably less rotation processing) (Moreau, Clerc, Mansy-Dannay, & Guerrien, 2012). Another study explored underlying mechanisms of this link and showed that wrestlers rely on motor processing during spatial problem-solving: while visual interference had negative effect on performance of all participants, motor interference impeded wrestlers performance in mental rotation task more strongly, compared to non-athletes (Moreau, 2012). These results were attributed to the wrestling-specific motor experience, i.e. body rotations in three-dimensional space. Another study explored the effect of judo on comprehensive set of SA measures (Meneghetti, Feraco, Ispiro, Pietsch, and Jansen (2021). Results showed that people who practice judo demonstrated better performance in some spatial tests (mental rotation, embedded figures, and water level tasks) but not in the others (object perspective task and wayfinding). These results were attributed to the "motor demands" of judo that requires monitoring of opponents' position and their body parts but does not require a large-scale ability to orient in an environment (Meneghetti et al., 2021).

Some sports, such as hockey, may rely on both small- and large-scale aspects of SA. Specifically, researchers and practitioners stated that hockey requires the ability to operate dynamic spatial and temporal representation, to match and coordinate spatial and temporal parameters of movement, and to orient in the limited gaming space (Clark & Maddocks, 2018; Fokin, Fetisova, & Egorov, 2019; Zaitsev & Varfolomeeva, 2019). In addition, hockey can be considered as an open skill sport (as one with fluid and shifting, externally driven, and highly variable context) along with soccer, tennis – a type of sport that could be particularly beneficial for spatial ability, as opposed to closed skill sports (repetitive and constant contexts) such as running and swimming (Becker, McClelland, Geldhof, Gunter, & MacDonald, 2018).

To our knowledge, very few studies empirically assessed different spatial skills of ice hockey players. For example, two studies reported positive associations between spatial orientation in virtual reality and high level of hockey training (Polikanova et al., 2021; Satrapová, Perič, & Rulík, 2021), although in these articles spatial orientation was understood not as a cognitive ability, but as a game skill (was measured with puck hitting and successful passes). Another study by Clark and Maddocks (2018) revealed that hockey players performed better in measures of visual selective attention than non-athlete controls. In contrast, one study did not find differences between retired professional hockey players and an age-matched group in visuospatial functions and visuospatial problem solving (Esopenko et al., 2017).

Moreover, there is mounting evidence that intensive engagement with sport, especially at the elite and professional level, might have a negative impact on cognition and academic performance, although the data is controversial (Jonker, Elferink-Gemser, & Visscher, 2009; Pinto-Escalona, Valenzuela, Esteban-Cornejo, & Martínez-de-Quel, 2022; Sallen, Wendeborn, & Gerlach, 2023; Wretman, 2017). For example, Becker and colleagues reported a curvilinear association between sport intensity and cognitive function, with high-intensity engagement with sports associated with worse executive functions and academic performance (maths scores, specifically) (Becker et al., 2018). In one recent study elite athletes showed lower overall academic performance than controls in most academic subjects, with no differences between sport types (Pinto-Escalona et al., 2022). However, it is still unclear what is the reason why sport engagement impairs academic performance and cognitive functioning. One explanation for lower results in elite athletes is them having a so called "dual career" – they need to contribute their limited time to both academic and sport achievement (Sallen et al., 2023; Storm & Eske, 2022). For example, inflexible academic timetables, strict training schedule, and stress due to time constraints might be potential reasons underlying the lower academic performance observed in young elite athletes (Cosh & Tully, 2014). Another explanation might be that intensive engagement in sport, especially in demanding sports (such as hockey and skating) may lead to fatigue and even to impairment in brain functioning (hippocampus specifically) due to chronic intensive metabolic demands (see Becker et al., 2018 for discussion). Given that hippocampus is one of the key regions for spatial information processing (Brunec et al., 2019; O'Keefe & Dostrovsky, 1971; Weisberg & Ekstrom, 2021), it is especially important to investigate effects of sport engagement on spatial ability. Furthermore, repetitive brain damage, associated with hockey, e.g. concussions (Johnson, 2011), might also be a reason for lower results in cognitive tests and academic achievement (McFarlane, Burles, Yeates, Schneider, & Iaria, 2020).

To summarize, current research in the links between physical activity and spatial ability is limited and complex (see review by Morawietz & Muehlbauer, 2021). Understanding of these mechanisms is important given that spatial ability is a core cognitive function for many aspects of life (Ishikawa & Newcombe, 2021) and is implicated in educational and career performance (Kell, Lubinski, Benbow, & Steiger, 2013; Shea, Lubinski, & Benbow, 2001). Furthermore, exploration of these mechanisms may help to understand complex links between sport and well-being, cognition (Buecker, Simacek, Ingwersen, Terwiel, & Simonsmeier, 2020; Logan, Henry, Hillman, & Kramer, 2022; Ludyga et al., 2020) and academic achievement more broadly (Barbosa et al., 2020; Sember, Jurak, Kovač, Morrison, & Starc, 2020).

The current study aims to test whether playing hockey at an elite level is associated with higher vs. lower spatial ability and academic grades. To achieve this aim, we compared two large samples of adolescents: male ice hockey players from elite junior teams and their unselected peers - on ten spatial ability tests, Raven's progressive matrices (a proxy of fluid intelligence), and school grades.

2. Methods

2.1. Participants

A priori power analysis was performed using GPower (v.3.1.9.7; Faul, Erdfelder, Lang, & Buchner, 2007). We expected a small-to-moderate effect size, based on the meta-analysis by Voyer and Jansen who reported a Cohen's d of 0.38 (CI 0.24, 0.52) for the overall athlete advantage in spatial ability and emphasized that the effects in individual studies were very heterogeneous (e.g., non-significant effects for open-skills sports). For an independent samples two-tailed *t*-test with an alpha level = 0.05 and expected power 0.8, the estimated sample size was 110 participants per group (274 for the lower boundary of confidence interval, 60 for the higher one).

In the current study, data were collected separately from two samples. The first group consisted of 278 adolescent boys (Mean age = 15.47, SD = 1.07) from general public schools. The second group consisted of 225 adolescent hockey players (Mean age = 14.25, SD = 0.57) who were selected for elite junior teams to participate in federal and international hockey competitions. All teams included only male players.

2.2. Procedure

The study was approved by the Ethics committee of the Interdisciplinary Research at Tomsk State University (code of ethical approval: 16012018–5).

All adolescents participated in the study voluntarily and were fully informed about the testing procedure. The participants' parents or legal guardians provided their written informed consent. Additionally, verbal assent was obtained from the children before the testing. All participants could refuse to participate at any moment without explaining the reasons.

The data was collected using the computerised battery. The participants performed tests in groups of up to 25 people. The duration of testing was limited to 1.5 h (equal to the duration of 2 school lessons). Due to this time limit, not all participants managed to complete the testing (for exact numbers for each test, please see Tables A1-A2 in the Appendix). Those participants who completed the tests only partially were retained for analysis, with the unfinished tests labelled as missing data. In the analysis, the missing values were excluded pairwise (per dependent variable).

2.3. Measures

Before the testing, all participants provided information regarding their age, gender, and the yearly school grades in 12 subjects.

2.3.1. King's challenge battery

Spatial ability was assessed using a gamified online battery "King's Challenge" (Rimfeld et al., 2017). This battery consists of 10 tests, assessing various facets of small-scale SA; for a detailed description of the subtests, see Table 1 retrieved from Budakova et al. (2021). The tests are linked by a storyline about building a castle and protecting it from attacks.

The battery was translated to Russian and validated with a student sample (Esipenko et al., 2018; Likhanov et al., 2018) and an adolescent sample (Budakova et al., 2021) with good validity shown for all tests. The battery was also shown to be suitable for use in both unselected and selected samples (Likhanov et al., 2021; Likhanov, Tsigeman, & Kovas, 2021).

2.3.2. Raven's progressive matrices

Raven's Progressive Matrices (Burke, 1972; Raven, 1941) were used as a proxy for 'g' or general cognitive ability (Jensen, 1998). This test consists of a series of incomplete patterns ("matrices") of increasing difficulty; in each case, a participant is asked to select the piece missing from the pattern among the options presented on the screen. In our testing, we used an abbreviated version: The sections A and B were omitted; only odd items were used from the sections C, D, and E; the most difficult section F was fully retained for the analysis. A total sum of all correct items was used for analysis. This method demonstrated good validity in previous studies (Budakova et al., 2021; Likhanov, Bogdanova, Alenina, Kolienko, & Kovas, 2023).

Table 1
Description of the 10 tests in the King's challenge battery.

Subtest name	N of items	Time limit per item (sec)	Description
Cross-sections	15	20	visualizing cross-sections of objects
2D drawing	5	45	sketching a 2D layout of a 3D object from a specified viewpoint
Pattern assembly	15	20	visually combining pieces of objects to make a whole figure
Elithorn mazes	10	7	joining together as many dots as possible from an array
Mechanical reasoning	16	25	multiple-choice naive physics questions
Paper folding	15	20	visualizing placement of holes, after they were punched through folded piece of paper
3D drawing	7	70	sketching a 3D drawing from a 2D diagram
Shape rotation	15	20	choosing the rotated target figure among others
Perspective taking	15	20	visualizing objects from a different perspective
Mazes	10	25	searching for a way through a 2D maze in a time-limited task
Total score for the battery	123	–	A sum of scores for all tests in the battery.

2.3.3. School grades

Participants reported their year grades for 12 school subjects. The assessment scale is from one to five, but only 'three' to 'five' are passing grades, with 'one' and 'two' being fail grades – small grading range is a problem, previously discussed in several studies (e.g., Budakova et al., 2021; Likhanov et al., 2021). To estimate overall level of academic achievement, we calculated composite grade by summing up results in 12 subjects into one continuous variable.

2.4. Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics (v. 26.0.0.0) and JASP (v 0.14.1).

Before the analysis, all data were standardized and screened for missing values, univariate, and multivariate outliers. The threshold of $Z = 3.29$ was used as recommended in Field (2009) to exclude outliers, and Mahalanobis distance was used to find multivariate outliers within two samples. In total, <5% of outliers were excluded. We regressed the age from SA and used the residuals for all further analyses. Additional analysis were also conducted with Raven's Progressive Matrices results regressed out from all spatial measures – to control for general intelligence difference across groups. Descriptive analyses of raw scores and all residuals are presented in the Appendix in Tables A1 – A2.

Skewness and kurtosis were within the acceptable range (from −2 to +2, as recommended by George & Mallery, 2010). We detected normality assumptions violations for some tests (by inspecting the distribution plots and using the Shapiro-Wilk method). Therefore, we performed a nonparametric Mann-Whitney *U* test to compare the groups on performance in these tests.

The assumption of homoscedasticity was also violated, as detected by the Levene's test. Therefore, we used Welch's version of *t*-test (as recommended in Delacre, Lakens, & Leys, 2017) for the group comparison.

Both parametric and nonparametric comparisons returned similar results, so we present only Welch's results in the main text. The results of Mann-Whitney test are presented in the Appendix in the Table A4. To estimate effect sizes, we used Cohen's d for Welch's test and rank biserial correlation used for Mann-Whitney (as recommended in Khamis, 2008).

To compare year grades with only three levels (see Table 3 for description of the distributions), we used non-parametric Mann-Whitney test. This was followed up by examining a composite measure of academic achievement, by summing grades for 12 subjects. The composite score ranged from 36 to 60 and was considered a continuous variable. The distribution didn't violate normality assumption but violated homoscedasticity assumption, thus we used Welch's test to compare academic achievement across two groups.

3. Results

Hockey players showed lower scores compared with unselected sample in all spatial tests and the total score of King's Challenge battery, with effect sizes (Cohen's d) ranging from 0.42 to 1.04. The smallest effects were shown for Elithorn mazes (0.42) and Mazes (0.55). Hockey players also showed lower total score for Raven's Progressive Matrices, with effect size of 0.41. See Table 2 and Fig. 1 for full results.

We repeated group comparisons of the spatial measures, controlling for Raven's score. Raven's total scores were regressed out from SA subtests, and the residuals were used for the analyses. The results of this comparison are presented in Table 2 and Fig. 2.

The differences between the two groups remained significant, with very similar effect sizes as for non-regressed scores.

We additionally compared the two groups on their self-reported school grades (see Table 3 for details). The results of non-parametric Mann-Whitney *U* test showed that the unselected sample had higher grades compared to hockey players in all 12 examined school subjects (rank biserial correlations: 0.24–0.51), with the largest effect-sizes for

Table 2
Independent Samples Welch's test for correct answers on SA and Raven's Progressive Matrices tasks in two samples.

	Analysis 1: only Age regressed out			Analysis 2: Age and Raven's Total Score are regressed out		
	Statistic	*Df*	*Cohen's d*	*Statistic*	*Df*	*Cohen's d*
Total score for Raven's matrices	3.85	265.02	0.41***	*Regressed out*		
Cross-sections	8.03	480.36	0.72***	5.72	262.42	0.69***
2D Drawing	8.33	428.12	0.79***	5.96	260.42	0.73***
Pattern assembly	8.55	479.70	0.77***	5.42	264.34	0.66***
Elithorn Maze	3.97	336.92	0.42***	2.17	262.07	0.26*
Mechanical Reasoning	7.57	437.32	0.70***	4.40	257.98	0.54***
Paper Folding	9.18	478.76	0.82***	6.84	254.78	0.83***
3D Drawing	10.96	365.95	0.98***	6.89	216.16	0.83***
Shape Rotation	7.41	474.62	0.67***	5.31	266.74	0.64***
Perspective Taking	6.90	472.68	0.62***	3.46	257.90	0.42***
Mazes	5.95	429.02	0.55***	4.73	253.02	0.58***
Total score for King's Challenge battery	11.60	470.56	1.04***	8.49	259.34	1.03***

* $p < 0.05$.
*** $p < 0.001$.

STEM-related disciplines (algebra, chemistry, physics). School grades correlated positively with SA Total score (r_s = 0.19–0.49) and Raven's (r_s = 0.13–0.36). In addition, large differences were found between hockey players and unselected sample in composite score for overall academic achievement (Cohen's d = 1.17), that correlated with Total SA (r_s = 0.43) and Raven's score (r_s = 0.29).

4. Discussion

Current research explored potential differences in small-scale spatial ability between elite hockey players and non-athletes. The unselected sample demonstrated better results compared to athletes in all tests. We also found advantage of the unselected sample for Raven's Progressive Matrices. The group differences in spatial ability remained significant even after controlling for Raven's scores. This result suggests that lower performance in small-scale spatial ability tasks in athletes is not fully explained by differences in fluent intelligence, highlighting partial separation of spatial ability from "g" (Malanchini et al., 2020; Rimfeld et al., 2017).

There are several potential explanations for the observed lower performance in small-scale spatial tasks of elite hockey players. One explanation for these results might be that intensive engagement in hockey (e.g. strict training schedule) leads to fatigue in short-term, exhaustion in long term and even to lower performance in memory and executive functions due to chronic intensive metabolic demands and related brain dysfunction (see Becker et al., 2018 for discussion). In addition, fatigue could also cause a decline in motivation (Boksem & Tops, 2008; Müller, Klein-Flügge, Manohar, Husain, & Apps, 2021), that in turn might negatively affect cognitive performance and overall academic achievement.

Moreover, the lower results in athletes might have been caused by acute fatigue, as we did not control for whether participants exercised or trained directly prior to the data collection session. Previous studies showed that intensive exercise can cause a decline in the decision-

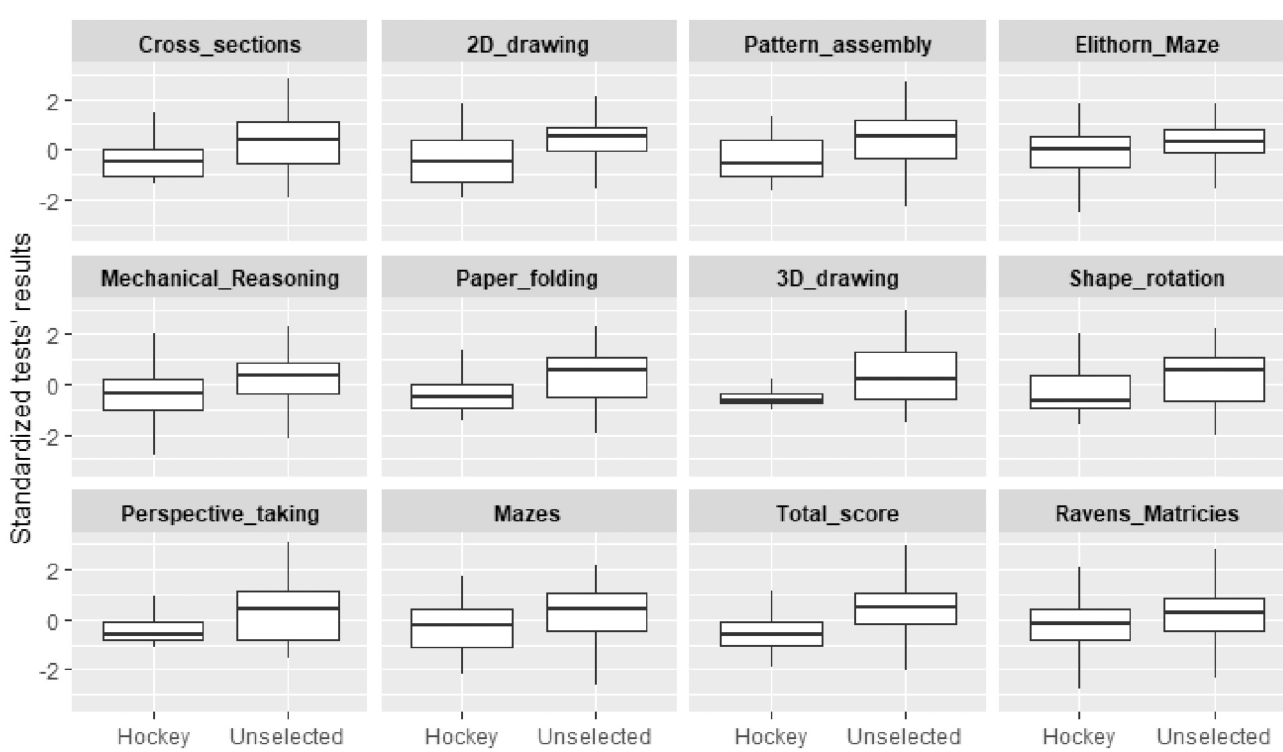

Fig. 1. Means for 10 SA tests, total score of SA battery and of Raven's Progressive Matrices for selected and unselected groups.
Note: All scores are in standardized residuals (age regressed out). The selected and unselected groups differed significantly for all tests presented. The middle line marks the median, 25 and 75 percentiles are represented by two hinges, and whiskers go for +/− 1.5 of interquartile range.

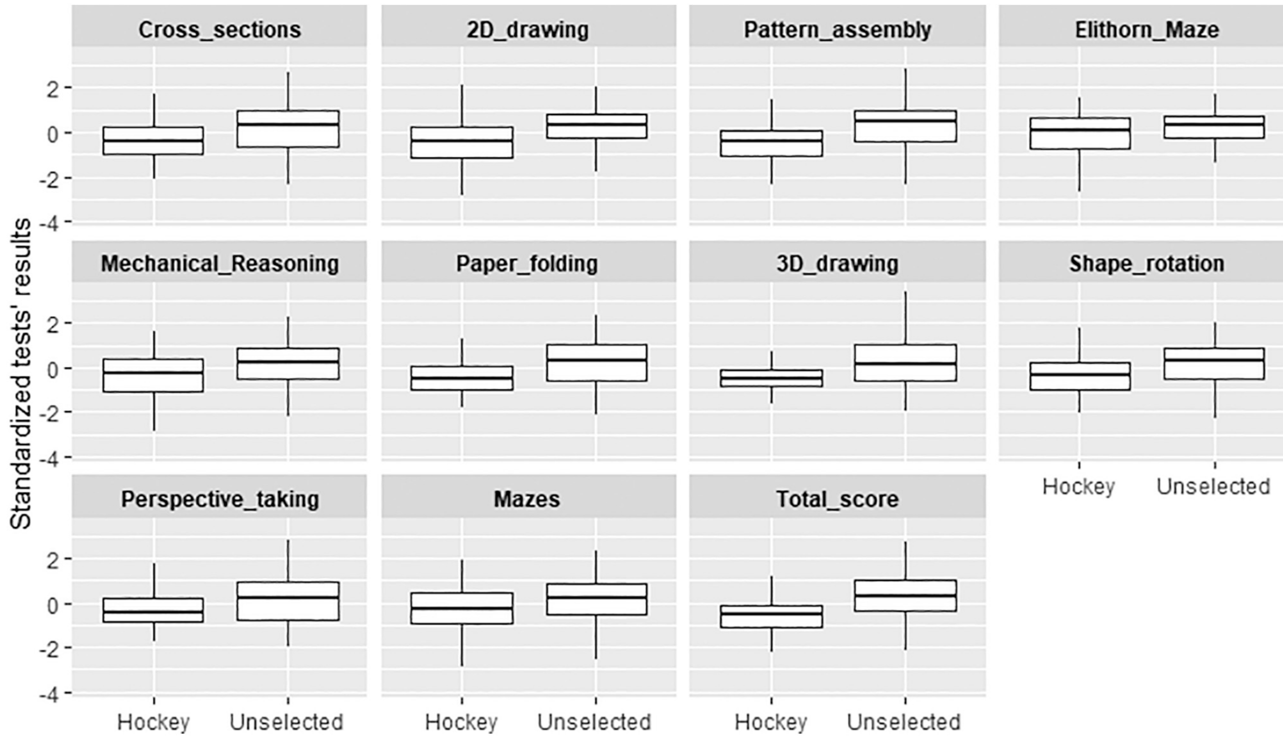

Fig. 2. Standardized residuals for correct answers on SA tasks in two samples (Raven's matrices results regressed out).
Note: All scores are in standardized residuals (age and Raven's scores regressed out). The selected and unselected groups differed significantly for all tests presented. The middle line marks the median, 25 and 75 percentiles are represented by two hinges, and whiskers go for +/− 1.5 of interquartile range.

Table 3
Comparison of school grades between two samples.

	Hockey		Unselected		Comparison	Correlations for the whole sample *(Spearman's rho)*	
	Mean	SD	Mean	SD	Rank biserial correlation	With Total score SA	With Total score Raven
Russian Language	3.93	0.59	4.40	0.60	0.38 ***	0.27***	0.19***
Algebra	3.88	0.67	4.56	0.58	0.51 ***	0.46***	0.36***
Geometry	3.94	0.65	4.55	0.58	0.48 ***	0.49***	0.35***
Informatics	4.42	0.62	4.74	0.48	0.27 ***	0.30***	0.17**
History	4.21	0.60	4.59	0.55	0.32 ***	0.21***	0.13**
Geography	4.28	0.56	4.60	0.54	0.30 ***	0.23***	0.15**
Biology	4.20	0.56	4.56	0.57	0.32 ***	0.26***	0.20***
Social Studies	4.34	0.60	4.61	0.54	0.24 ***	0.19***	0.15**
Physics	3.94	0.66	4.60	0.55	0.51 ***	0.47***	0.27**
Chemistry	3.98	0.61	4.53	0.60	0.45 ***	0.36***	0.27***
Foreign Language	4.12	0.68	4.58	0.56	0.36 ***	0.30***	0.17***
Literature	4.29	0.58	4.59	0.56	0.27 ***	0.22***	0.15***
Composite score	*49.13*	*4.99*	*54.98*	*4.98*	*Cohen's d = 1.17****	*0.43****	*0.29****

** $p < 0.01$.
*** $p < 0.001$.

making, attention, and perception abilities of players straight after the training (see e.g. a scoping review; Skala & Zemková, 2022). For hockey players, release of hormones during the game, can lead decline in working memory (Malcolm, Cooper, Folland, Tyler, & Sunderland, 2022). These results are relevant to planning sport and academic schedules for elite athletes, as well as schoolchildren in regular schools.

Moreover, long-term consequences of sport-related head traumas might be another explanation. As was shown in previous studies, concussions are very common among hockey players: around 25% of junior hockey players sustain at least one concussion in a single season (Echlin et al., 2010); and concussions account for 14% to 30% of all hockey-related head injuries, with rates of 5.8 to 6.1 concussions per 100 games (Andrews et al., 2022). This in turn could affect performance in complex cognitive tasks, including spatial (McFarlane et al., 2020). In addition, repetitive brain damage in frontal areas have been linked to decline in executive function, including in elite athletes (Logan et al., 2022; Seichepine et al., 2013). This in turn might lead to problems with regulation of emotions (Bailes, Dashnaw, Petraglia, & Turner, 2014) and increased levels of aggression and anxiety, contributing to lower academic achievement (Papageorgiou et al., 2020).

Yet another major factor contributing to lower performance in athletes might be time and effort allocation. Previous research suggested that people engage with activity in which they are successful (for example, in mathematics; Garon-Carrier et al., 2016), as per *relevant skills hypothesis* (Winner, Casey, Dasilva, & Hayes, 1991) and self-selection (Likhanov et al., 2023). It is possible that children with higher small-scale spatial ability tend to be more successful in academic domains, especially in STEM (Tsigeman et al., 2023). This, in turn, strengthens their motivation in these domains and leads to even greater spatial ability (Rich get richer, known as Mathew effect in education

(Walberg & Tsai, 1983), as many school subjects are linked to small-scale SA (Buckley, Seery, & Canty, 2018). In contrast, children with lower spatial ability and associated lower academic performance may show greater motivation in non-academic pursuits, including intensive sports engagement. In turn, this intensive engagement is very time demanding and puts the pressure of a “dual career” (Pinto-Escalona et al., 2022), thus leading to lower academic performance as per *investment theory* (theory by Cattell, 1987; empirical examples - e.g., Coyle, 2019).

Finally, the absence of positive effects might be that the hockey-relevant aspects of cognition were not tapped into with the measures used in the current study. Hockey may have positive effects on sustained alertness, efficient voluntary orientation, efficient processing of abrupt stimulus events; executive functions and other skills (Enns & Richards, 1997; Poltavski & Biberdorf, 2014). Specifically to spatial ability, engagement with hockey might primarily train dynamic and large-scale spatial ability, such as orientation and navigation (Uttal et al., 2013; Wang et al., 2014). We did not measure these skills in the present study. However, previous research suggested that small- and large-scale SA are closely linked (Likhanov et al., 2022; Malanchini et al., 2020), and that training of one type of SA can improve another (Jansen, Wiedenbauer, & Hahn, 2010; Likhanov et al., 2022). Therefore, one could expect if there was a positive effect of hockey on large-scale spatial ability, it would be found in tests tapping into small-scale spatial ability. We found no such effect even in Perspective taking – the task that can be considered as tapping into large-scale SA (Hegarty, 2004), although the group differences were somewhat smaller for this test.

Nevertheless, research into aetiology of spatial ability suggested that much of the variance in SA was explained by measure-specific environmental factors, including measurement error (Malanchini et al., 2020). Some of this variance may be partially explained by differential activities, including engagement in particular sports. In our study, there is some indirect evidence for this hypothesis. A somewhat lower effect size for differences between athletes and unselected groups was found in Elithorn mazes task – a task that required a rapid response (0.26 vs. 0.42 – the next lowest effect for Perspective taking), which may be linked to velocity demands in hockey. Hockey players perform frequent speed changes, attain marked acceleration and deceleration in a short time, and can reach high skating velocity (Dillman, Stockholm, & Greer, 1984). High speed of game demands fast reaction to a visual stimulus, good visual discrimination among competing visual stimuli, and ability to rapidly shift focus between near and far objects (Poltavski and Biberdorf, 2014). Further research is needed into specificity of effects, as our sample did not allow to compare hockey with other sports, evaluate intensity of engagement (amateur vs. professional), or explore gender effects (Tsigeman et al., 2023).

5. Conclusion

This study did not find positive associations between intensive engagement with hockey and small-scale spatial ability. These results suggest that sport effects on cognition may be complex: SA facet-specific, sport-specific, professional and intensity level-specific. Clarifying these effects will help develop nuanced educational and training programmes, maximising the positive potential and minimising the negative impact associated with engagement with elite sports on young athletes' cognitive and academic performance.

Funding

This work was supported by the Russian Science Foundation [grant number 23-18-00142].

CRediT authorship contribution statement

Ksenia Bartseva: Formal analysis, Writing – original draft. **Maxim Likhanov:** Conceptualization, Methodology, Resources, Software, Writing – review & editing. **Elina Tsigeman:** Formal analysis, Writing – review & editing. **Evgenia Alenina:** Formal analysis, Writing – review & editing. **Ivan Reznichenko:** Investigation, Resources, Writing – review & editing. **Elena Soldatova:** Investigation, Resources, Writing – review & editing. **Yulia Kovas:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

Elena L. Soldatova reports financial support was provided by Russian Science Foundation.

Data availability

The authors do not have permission to share data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.intell.2023.101805.

References

Andrews, E., Jildeh, T. R., Abbas, M. J., Lindsay-Rivera, K., Berguson, J., & Okoroha, K. R. (2022). Concussions in the national hockey league: analysis of incidence, return to play, and performance. *Orthopaedic Journal of Sports Medicine, 10*(1). https://doi.org/10.1177/23259671211052069, 23259671211052068.

Bailes, J. E., Dashnaw, M. L., Petraglia, A. L., & Turner, R. C. (2014). *Cumulative effects of repetitive mild traumatic brain injury*. https://doi.org/10.1159/000358765

Barbosa, A., Whiting, S., Simmonds, P., Scotini Moreno, R., Mendes, R., & Breda, J. (2020). Physical activity and academic achievement: An umbrella review. *International Journal of Environmental Research and Public Health, 17*(16), 5972. https://doi.org/10.3390/ijerph17165972

Becker, D. R., McClelland, M. M., Geldhof, G. J., Gunter, K. B., & MacDonald, M. (2018). Open-skilled sport, sport intensity, executive function, and academic achievement in grade school children. *Early Education and Development, 29*(7), 939–955. https://doi.org/10.1080/10409289.2018.1479079

Boksem, M. A. S., & Tops, M. (2008). Mental fatigue: Costs and benefits. *Brain Research Reviews, 59*(1), 125–139. https://doi.org/10.1016/j.brainresrev.2008.07.001

Brunec, I. K., Robin, J., Patai, E. Z., Ozubko, J. D., Javadi, A., Barense, M. D., … Moscovitch, M. (2019). Cognitive mapping style relates to posterior–anterior hippocampal volume ratio. *Hippocampus, 29*, 748–754. https://doi.org/10.1002/hipo.23072

Buckley, J., Seery, N., & Canty, D. (2018). A heuristic framework of spatial ability: A review and synthesis of spatial factor literature to support its translation into STEM education. *Educational Psychology Review, 30*(3), 947–972. https://doi.org/10.1007/s10648-018-9432-z

Budakova, A. V., Likhanov, M. V., Toivainen, T., Zhurbitskiy, A. V., Sitnikova, E. O., Bezrukova, E. M., & Kovas, Y. (2021). Measuring spatial ability for talent identification, educational assessment, and support: Evidence from adolescents with high achievement in science, arts, and sports. *Psychology in Russia: State of the Art, 14*(2), 59–85. https://doi.org/10.11621/pir.2021.0205

Buecker, S., Simacek, T., Ingwersen, B., Terwiel, S., & Simonsmeier, B. A. (2020). Physical activity and subjective well-being in healthy individuals: A meta-analytic review. *Health Psychology Review, 0*(0), 1–19. https://doi.org/10.1080/17437199.2020.1760728

Burke, H. R. (1972). Raven's progressive matrices: Validity, reliability, and norms. *The Journal of Psychology: Interdisciplinary and Applied, 82*(2), 253–257. https://doi.org/10.1080/00223980.1972.9923815

Cattell, R. B. (1987). *Intelligence: Its structure, Growth and Action*. Elsevier.

Clark, K., & Maddocks, M. (2018). Enhanced visual attention in university hockey players. *Journal of Vision, 18*(10), 1120. https://doi.org/10.1167/18.10.1120

Cosh, S., & Tully, P. J. (2014). "All I have to do is pass": A discursive analysis of student athletes' talk about prioritising sport to the detriment of education to overcome stressors encountered in combining elite sport and tertiary education. *Psychology of Sport and Exercise, 15*(2), 180–189. https://doi.org/10.1016/j.psychsport.2013.10.015

Coyle, T. R. (2019). Tech tilt predicts jobs, college majors, and specific abilities: Support for investment theories. *Intelligence, 75*, 33–40. https://doi.org/10.1016/j.intell.2019.04.002

Delacre, M., Lakens, D., & Leys, C. (2017). Why Psychologists Should by Default Use Welch's t-test Instead of Student's t-test. *International Review of Social Psychology, 30*(1), 92–101.DOI. https://doi.org/10.5334/irsp.82

Devlin, A. S. (2004). Sailing experience and sex as correlates of spatial ability. *Perceptual and Motor Skills, 98*(3 Pt 2), 1409–1421. https://doi.org/10.2466/pms.98.3c.1409-1421

Dillman, C. J., Stockholm, A. J., & Greer, N. (1984). Movement of ice hockey players. In *ISBS - Conference Proceedings Archive.*. https://ojs.ub.uni-konstanz.de/cpa/article/view/1410.

Echlin, P. S., Tator, C. H., Cusimano, M. D., Cantu, R. C., Taunton, J. E., Upshur, R. E. G., … Skopelja, E. N. (2010). A prospective study of physician-observed concussions during junior ice hockey: Implications for incidence rates. *Neurosurgical Focus, 29*(5), E4. https://doi.org/10.3171/2010.9.FOCUS10186

Enns, J. T., & Richards, J. C. (1997). Visual attentional orienting in developing hockey players. *Journal of Experimental Child Psychology, 64*(2), 255–275. https://doi.org/10.1006/jecp.1996.2348

Esipenko, E., Maslennikova, E. P., Budakova, A., Sharafieva, K., Victoria, I., Feklicheva, I., … Malykh, S. (2018). Comparing spatial ability of male and female students completing humanities vs. technical degrees. *Psychology in Russia: State of the Art, 11*, 37–49. https://doi.org/10.11621/pir.2018.0403

Esopenko, C., Chow, T. W., Tartaglia, M. C., Bacopulos, A., Kumar, P., Binns, M. A., … Levine, B. (2017). Cognitive and psychosocial function in retired professional hockey players. *Journal of Neurology, Neurosurgery, and Psychiatry, 88*(6), 512–519. https://doi.org/10.1136/jnnp-2016-315260

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Field, A. P. (2009). *Discovering statistics using SPSS: And sex, drugs and rock 'n' roll* (3rd ed.). SAGE Publications.

Fokin, A. M., Fetisova, S. L., & Egorov, V. (2019). Formirovanie individual'nogo takticheskogo myshleniya u hokkeistov na etape nachal'noj specializacii. In *, 192. Izvestiya Rossijskogo gosudarstvennogo pedagogicheskogo universiteta im. A. I. Gercena* (Article 192. in Russian).

Garon-Carrier, G., Boivin, M., Guay, F., Kovas, Y., Dionne, G., Lemelin, J.-P., … Tremblay, R. E. (2016). Intrinsic motivation and achievement in mathematics in elementary school: A longitudinal investigation of their association. *Child Development, 87*(1), 165–175. https://doi.org/10.1111/cdev.12458

George, D., & Mallery, M. (2010). *SPSS for Windows Step by Step: A Simple Guide and Reference, 17.0 Update* (10th Edition). Boston: Pearson.

Hegarty, M. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence, 32*(2), 175–191. https://doi.org/10.1016/j.intell.2003.12.001

Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence, 34*(2), 151–176. https://doi.org/10.1016/j.intell.2005.09.005

Hegarty, M., & Waller, D. A. (2005). Individual differences in spatial abilities. In P. Shah, & A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (1st ed., pp. 121–169). Cambridge University Press. https://doi.org/10.1017/CBO9780511610448.005.

Ishikawa, T., & Newcombe, N. S. (2021). Why spatial is special in education, learning, and everyday activities. *Cognitive Research: Principles and Implications, 6*(1), 20. https://doi.org/10.1186/s41235-021-00274-5

Jansen, P. (2009). The dissociation of small- and large-scale spatial abilities in school-age children. *Perceptual and Motor Skills, 109*, 357–361. https://doi.org/10.2466/pms.109.2.357-361

Jansen, P. (2016). Golf training: A new possibility to counteract decline in visual-spatial abilities? *Journal of Gerontology & Geriatric Research, 05*. https://doi.org/10.4172/2167-7182.1000375

Jansen, P., Kellner, J., & Rieder, C. (2013). *The improvement of mental rotation performance in second graders after creative dance training*. https://doi.org/10.4236/CE.2013.46060

Jansen, P., Wiedenbauer, G., & Hahn, N. (2010). Manual rotation training improves direction-estimations in a virtual environmental space. *European Journal of Cognitive Psychology, 22*, 6–17. https://doi.org/10.1080/09541440802678487

Jensen, A. R. (1998). *The G Factor: The Science of Mental Ability*. Westport, CT: Praeger/Greenwood.

Johnson, L. S. M. (2011). Concussion in youth ice hockey: It's time to break the cycle. *CMAJ : Canadian Medical Association Journal, 183*(8), 921–924. https://doi.org/10.1503/cmaj.110282

Jonker, L., Elferink-Gemser, M. T., & Visscher, C. (2009). Talented athletes and academic achievements: A comparison over 14 years. *High Ability Studies, 20*(1), 55–64. https://doi.org/10.1080/13598130902863691

Kell, H. J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Creativity and technical innovation: Spatial ability's unique role. *Psychological Science, 24*(9), 1831–1836. https://doi.org/10.1177/0956797613478615

Khamis, H. (2008). Measures of Association: How to Choose? *Journal of Diagnostic Medical Sonography, 24*(3), 155–162. https://doi.org/10.1177/8756479308317006

Likhanov, M., Bogdanova, O., Alenina, E., Kolienko, T., & Kovas, Y. (2023). No evidence of a positive effect of learning Chinese language as an L2 on spatial ability. *Scientific Reports, 13*(1), 1262. https://doi.org/10.1038/s41598-022-26738-2

Likhanov, M., Ismatullina, V. I., Fenin, A. Y., Wei, W., Rimfeld, K., Maslennikova, E. P., … Kovas, Y. V. (2018). The factorial structure of spatial abilities in Russian and Chinese students. *Psychology in Russia: State of the Art, 11*(4), 96–114. https://doi.org/10.11621/pir.2018.0407

Likhanov, M., Maslennikova, E., Costantini, G., Budakova, A., Esipenko, E., Ismatullina, V., & Kovas, Y. (2022). This is the way: Network perspective on targets for spatial ability development programmes. *British Journal of Educational Psychology, 92*(4), 1597–1620.

Likhanov, M., Tsigeman, E., & Kovas, Y. (2021). *Online short spatial ability battery (OSSAB): Psychometric norms for high school students* (pp. 117–129). https://doi.org/10.17223/17267080/78/7

Likhanov, M. V., Tsigeman, E. S., Papageorgiou, K. A., Akmalov, A. F., Sabitov, I. A., & Kovas, Y. V. (2021). Ordinary extraordinary: Elusive group differences in personality and psychological difficulties between STEM-gifted adolescents and their peers. *British Journal of Educational Psychology, 91*(1), 78–100. https://doi.org/10.1111/bjep.12349

Logan, N. E., Henry, D. A., Hillman, C. H., & Kramer, A. F. (2022). Trained athletes and cognitive function: A systematic review and meta-analysis. *International Journal of Sport and Exercise Psychology, 0*(0), 1–25. https://doi.org/10.1080/1612197X.2022.2084764

Ludyga, S., Gerber, M., Pühse, U., Looser, V. N., & Kamijo, K. (2020). Systematic review and meta-analysis investigating moderators of long-term effects of exercise on cognition in healthy individuals. *Nature Human Behaviour, 4*(6), 603–612. https://doi.org/10.1038/s41562-020-0851-8

Malanchini, M., Rimfeld, K., Shakeshaft, N. G., McMillan, A., Schofield, K. L., Rodic, M., … Plomin, R. (2020). Evidence for a unitary structure of spatial cognition beyond general intelligence. *Npj Science of Learning, 5*(1), 1–13. https://doi.org/10.1038/s41539-020-0067-8

Malcolm, R., Cooper, S., Folland, J. P., Tyler, C. J., & Sunderland, C. (2022). The influence of a competitive Field hockey match on cognitive function. *Frontiers in Human Neuroscience, 16*, Article 829924. https://doi.org/10.3389/fnhum.2022.829924

McFarlane, L. H., Burles, F., Yeates, K. O., Schneider, K., & Iaria, G. (2020). A pilot study evaluating the effects of concussion on the ability to form cognitive maps for spatial orientation in adolescent hockey players. *Brain Injury, 34*(8), 1112–1117. https://doi.org/10.1080/02699052.2020.1773537

Meneghetti, C., Feraco, T., Ispiro, P., Pietsch, S., & Jansen, P. (2021). The practice of judo: How does it relate to different spatial abilities? *Spatial Cognition & Computation, 21*(1), 67–88. https://doi.org/10.1080/13875868.2020.1830995

Morawietz, C., & Muehlbauer, T. (2021). Effects of physical exercise interventions on spatial orientation in children and adolescents: A systematic scoping review. *Frontiers in Sports and Active Living, 3*, 156. https://doi.org/10.3389/fspor.2021.664640

Moreau, D. (2012). The role of motor processes in three-dimensional mental rotation: Shaping cognitive processing via sensorimotor experience. *Learning and Individual Differences, 22*(3), 354–359. https://doi.org/10.1016/j.lindif.2012.02.003

Moreau, D., Clerc, J., Mansy-Dannay, A., & Guerrien, A. (2012). Enhancing spatial ability through sport practice: Evidence for an effect of motor training on mental rotation performance. *Journal of Individual Differences, 33*(2), 83–88. https://doi.org/10.1027/1614-0001/a000075

Müller, T., Klein-Flügge, M. C., Manohar, S. G., Husain, M., & Apps, M. A. J. (2021). Neural and computational mechanisms of momentary fatigue and persistence in effort-based choice. *Nature Communications, 12*(1). https://doi.org/10.1038/s41467-021-24927-7. Article 1.

O'Keefe, J., & Dostrovsky, J. (1971). The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat. *Brain Research, 34*(1), 171–175. https://doi.org/10.1016/0006-8993(71)90358-1

Papageorgiou, K. A., Likhanov, M., Costantini, G., Tsigeman, E., Zaleshin, M., Budakova, A., & Kovas, Y. (2020). Personality, behavioral strengths and difficulties and performance of adolescents with high achievements in science, literature, art and sports. *Personality and Individual Differences, 160*, Article 109917. https://doi.org/10.1016/j.paid.2020.109917

Pietsch, S., & Jansen, P. (2018). Climbing sports effect specific visual-spatial abilities. *Journal of Imagery Research in Sport and Physical Activity, 13*(1). https://doi.org/10.1515/jirspa-2017-0012

Pinto-Escalona, T., Valenzuela, P. L., Esteban-Cornejo, I., & Martínez-de-Quel, Ó. (2022). Sport participation and academic performance in young elite athletes. *International Journal of Environmental Research and Public Health, 19*(23). https://doi.org/10.3390/ijerph192315651. Article 23.

Polikanova, I., Yakushina, A., Leonov, S., Kruchinina, A., Chertopolokhov, V., & Liutsko, L. (2021). *Study of differences in motor reactions and performances in professional ice hockey players and not experienced participants using virtual reality (VR) technology*. https://doi.org/10.20944/preprints202103.0776.v1

Poltavski, D., & Biberdorf, D. (2014). The role of visual perception measures used in sports vision programmes in predicting actual game performance in division I collegiate hockey players. *Journal of Sports Sciences, 33*, 1–12. https://doi.org/10.1080/02640414.2014.951952

Raven, J. C. (1941). Standardization of progressive matrices, 1938. *British Journal of Medical Psychology, 19*, 137–150. https://doi.org/10.1111/j.2044-8341.1941.tb00316.x

Rimfeld, K., Shakeshaft, N., Malanchini, M., Rodic, M., Selzam, S., Schofield, K., Dale, P., Kovas, Y., & Plomin, R. (2017). Phenotypic and genetic evidence for a unifactorial structure of spatial abilities. *Proceedings of the National Academy of Sciences, 114*, 201607883. https://doi.org/10.1073/pnas.1607883114

Sallen, J., Wendeborn, T., & Gerlach, E. (2023). Talented athletes as high achievers—Only in sports? Analysis of academic performance and the impact of dual career assistance programmes in upper secondary school. *German journal of exercise and sport Research.*. https://doi.org/10.1007/s12662-023-00878-7

Satrapová, P., Perič, T., & Rulík, A. (2021). *Virtual reality as a training tool for the development of ice hockey thinking. 13*.

Seichepine, D. R., Stamm, J. M., Daneshvar, D. H., Riley, D. O., Baugh, C. M., Gavett, B. E., … Stern, R. A. (2013). Profile of self-reported problems with executive functioning in college and professional football players. *Journal of Neurotrauma, 30*(14), 1299–1304. https://doi.org/10.1089/neu.2012.2690

Sember, V., Jurak, G., Kovač, M., Morrison, S. A., & Starc, G. (2020). Children's physical activity, academic performance, and cognitive functioning: A systematic review and

Meta-analysis. *Frontiers in Public Health, 8*, 307. https://doi.org/10.3389/fpubh.2020.00307

Shea, D., Lubinski, D., & Benbow, C. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology, 93*, 604–614. https://doi.org/10.1037/0022-0663.93.3.604

Skala, F., & Zemková, E. (2022). Effects of acute fatigue on cognitive performance in team sport players: Does it change the way they perform? A scoping review. *Applied Sciences, 12*(3). https://doi.org/10.3390/app12031736. Article 3.

Storm, R. K., & Eske, M. (2022). Dual careers and academic achievements: Does elite sport make a difference? *Sport, Education and Society, 27*(6), 747–760. https://doi.org/10.1080/13573322.2021.1919070

Tsigeman, E. S., Likhanov, M. V., Budakova, A. V., Akmalov, A., Sabitov, I., Alenina, E., … Kovas, Y. (2023). Persistent gender differences in spatial ability, even in STEM experts. *Heliyon, 9*(4), Article e15247. https://doi.org/10.1016/j.heliyon.2023.e15247

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin, 139*(2), 352–402. https://doi.org/10.1037/a0028446

Voyer, D., & Jansen, P. (2017). Motor expertise and performance in spatial tasks: A meta-analysis. *Human Movement Science, 54*, 110–124. https://doi.org/10.1016/j.humov.2017.04.004

Walberg, H. J., & Tsai, S.-L. (1983). 'Matthew' effects in education. *American Educational Research Journal, 20*(3), 359–373. https://doi.org/10.2307/1162605

Wang, L., Cohen, A. S., & Carr, M. (2014). Spatial ability at two scales of representation: A meta-analysis. *Learning and Individual Differences, 36*, 140–144. https://doi.org/10.1016/j.lindif.2014.10.006

Weigelt, M., & Memmert, D. (2020). The mental rotation ability of expert basketball players: Identifying on-court plays. *Research Quarterly for Exercise and Sport, 92*(1), 137–145. https://doi.org/10.1080/02701367.2020.1713289

Weisberg, S. M., & Ekstrom, A. D. (2021). Hippocampal volume and navigational ability: The map(ping) is not to scale. *Neuroscience and Biobehavioral Reviews, 126*, 102–112. https://doi.org/10.1016/j.neubiorev.2021.03.012

Winner, E., Casey, M. B., Dasilva, D., & Hayes, R. (1991). Spatial abilities and Reading deficits in visual art students. *Empirical Studies of the Arts, 9*(1), 51–63. https://doi.org/10.2190/528M-DXT5-WUJA-W297

Wretman, C. J. (2017). School sports participation and academic achievement in middle and high school. *Journal of the Society for Social Work and Research, 8*(3), 399–420. https://doi.org/10.1086/693117

Zaitsev, E. S., & Varfolomeeva, Z. S. (2019). Osobennosti psihomotornogo sostoyaniya hokkeistov-vratarej na etape nachal'noj sportivnoj specializacii. *Sciences of Europe, 35-4*(35) (Article 35-4 (35). in Russian).