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# Cognitive Ageing in Top-Level Female Soccer Players Compared to a Normative Sample from the General Population: A Cross-sectional Study

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**Abstract**

**Objective:** There is an ongoing debate on the potential negative effect of contact sport participation on long-term neurocognitive performance due to inherent exposure to concussive and subconcussive head impacts. The aim of the present study was to investigate whether cognitive ageing is exacerbated in elite soccer players compared to the general population. **Method:** Neurocognitive performance in 6 domains was compared between 240 elite soccer players and a normative sample from the general population ($n = 585$) using the computerised test battery CNS Vital Signs. We used two-way factorial ANOVA to analyse the interaction between age groups (15–19, 20–29, 30–39, 40–49 years) and study population (female soccer players vs. norm sample) in their effects on neurocognitive performance. **Results:** We found no significant interaction effect of age group and study population in five of six test domains. For processing speed, the effect of age was more pronounced in female soccer players ($F = 16.89$, $p = .002$). Further, there was a clear main effect of study population on neurocognitive performance with generally better scores in soccer players. **Conclusions:** Elite female soccer players generally performed better than the norm sample on tests of cognitive function, and further, cognitive ageing effects were similar in elite soccer players and controls in all but one domain. A lifespan approach may facilitate insightful future research regarding questions related to long-term neurocognitive health in contact sport athletes.

**Keywords:** Age-related cognitive decline, Neurocognitive performance, CNS vital signs, Concussion, Football, Ageing athlete

## INTRODUCTION

There is an extensive ongoing debate in the media as well as in the scientific literature on the potential negative effect of contact and collision sport participation on long-term neurocognitive function (Casson & Viano, 2019; Manley et al., 2017; Putukian et al., 2019). Specifically, it was suggested that the inherent exposure to (repeated) concussions or subconcussive blows may lead to an increased risk or earlier onset of neurodegenerative diseases and psychiatric disorders (Chiò, Benzi, Dossena, Mutani, & Mora, 2005; Kerr, Marshall, Harding, & Guskiewicz, 2012; Lehman, Hein, Baron, & Gersic, 2012; Mackay et al., 2019), declines in neurocognitive performance (Hume et al., 2017; Pearce, Rist, Fraser, Cohen, & Maller, 2018), and neuroimaging abnormalities (Koerte et al., 2016; Strain et al., 2015) in retired athletes. While most research on the topic has been conducted with American soccer players (Manley et al., 2017), similar findings have also been reported in rugby (Hume et al., 2017; Pearce et al., 2018), ice hockey (Tremblay et al., 2013), and soccer (soccer) (Chiò et al.,

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2005; Koerte et al., 2016; Mackay et al., 2019). However, other studies with retired contact sport athletes report no such effects related to the prevalence of neurodegenerative diseases and psychiatric disorders (Deshpande et al., 2017; McMillan et al., 2017; Vann Jones, Breakey, & Evans, 2014), neurocognitive performance (Esopenko et al., 2017; McMillan et al., 2017), or neuroimaging abnormalities (Zivadinov et al., 2018).

The results regarding the long-term effect of repeated subconcussive head impacts (RSHI) as experienced when heading the ball in soccer are similarly inconsistent (Putukian et al., 2019). It has been suggested that exposure to RSHI in soccer may lead to neuronal damage comparable to that of repetitive concussions (Maher, Hutchison, Cusimano, Comper, & Schweizer, 2014). Due to the growing public concern, the US Soccer Federation recently banned heading in children under the age of 10 years. The first studies on the topic were conducted in the early 1990s by Tysvaer and Lochen (1991), who found mild to severe neuropsychologic deficits in former soccer players compared to a control group, with a higher prevalence of impairment in “typical headers”. However, more recently, two systematic reviews on the topic involving mostly active soccer players found no convincing evidence for this association (Kontos et al., 2017; Tarnutzer, Straumann, Brugger, & Feddermann-Demont, 2017). Interestingly, both meta-analyses noted that studies involving more senior or retired athletes were more likely to report adverse outcomes. Thus, it is possible that some of the inconsistencies in the literature stem from a lack of differentiation between studies involving active versus retired athletes.

Several underlying mechanisms were proposed to explain the link between repeated head impacts and negative long-term outcomes. One compelling hypothesis states that RSHI and concussion may accelerate the otherwise normal cognitive ageing process and thus lead to exacerbated cognitive decline and earlier clinical manifestation of neurodegenerative diseases (Broglio, Eckner, Paulson, & Kutcher, 2012; Moretti et al., 2012). In normal brain ageing, peak performance in fluid cognitive abilities is achieved during the third decade of life and declines gradually thereafter (Salthouse, 2010). Specifically, speed-related domains are characterised by a nearly linear decline, while memory and reasoning show modest declines until 60 years of age and accelerating declines thereafter (Salthouse, 2019). These cognitive changes are accompanied by structural and functional changes in the brain, including alterations in neuronal structure, loss of synapses, and dysfunction of neuronal networks (Gunning-Dixon, Brickman, Cheng, & Alexopoulos, 2009; Morrison & Hof, 1997). The theory linking (sub)concussive head impacts to accelerated cognitive decline proposes that in individuals with previous head injuries less ageing-related neuronal loss is needed to produce a clinically observable deficit (Figure 1) (Moretti et al., 2012). Based on the neuropsychological profiles of concussions and cognitive ageing, any adverse effects up to middle age may be most apparent in speed-related domains.

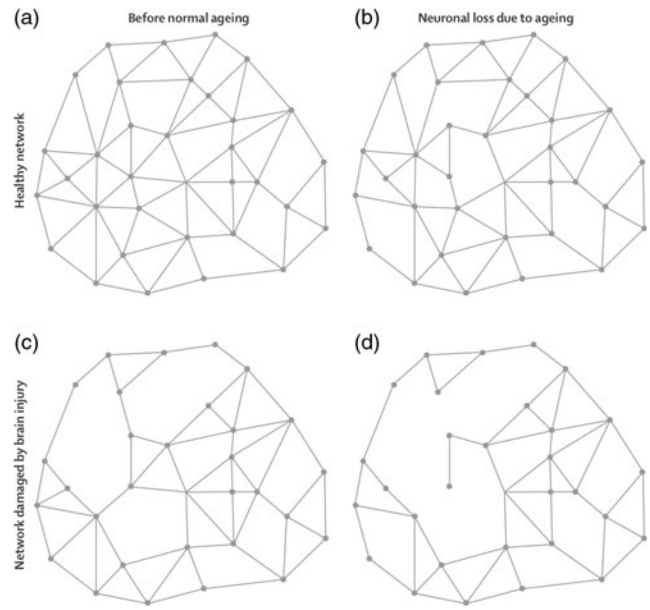


**Fig. 1.** Hypothetical changes in neural networks in normal ageing and after brain injury. (a) healthy network, (b) healthy network with age-related neuronal loss, (c) network damaged by brain injury, (d) network damaged by brain injury and with age-related neuronal loss. Copyright 2012 by Elsevier. Reprinted with permission from Moretti et al. (2012).

To date, only a limited number of studies have assessed whether a differential ageing effect can be observed on neurocognitive or neuroimaging measures in retired contact sport athletes (Esopenko et al., 2017; Koerte et al., 2016; Tremblay et al., 2013). Tremblay et al. (2013) reported an interaction between age and group, when comparing ventricular volume and cortical thickness between concussed and non-concussed ice hockey and American soccer players. A significantly greater decrease in cortical thickness with age was also found in retired soccer players compared to non-contact sport controls (Koerte et al., 2016). Further, greater exposure to RSHI was correlated with thinner cortex, and thinner cortex was predictive for lower processing speed in the same sample. However, a recent study by Esopenko et al. (2017) found no differential ageing effect on neurocognitive performance in retired ice hockey players relative to a control group. Thus, while there is some evidence supporting the accelerated decline hypothesis in relation to changes in brain structure, an analogous relationship has not been reported for neurocognitive measures.

These inconsistencies may partly be due to several methodological difficulties including very small sample sizes, ambiguity of concussion definition and diagnosis, and issues with recall bias when assessing concussion history or RSHI exposure retrospectively. In the present study, we will therefore not attempt to quantify these variables, but assess cognitive ageing in a large sample of athletes at high risk for RSHI and concussions relative to a normative sample. We chose to analyse female soccer players as soccer players have an inherently high exposure to RSHI (heading) and concussions,

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and previous literature has almost exclusively focused on male athletes. This is an important gap in the literature as female soccer players have a higher incidence of concussions compared to male soccer players (Prien, Grafe, Rossler, Junge, & Verhagen, 2018) and, additionally, may be particularly vulnerable to the (long-term) effects of repetitive head impacts (Covassin, Savage, Bretzin, & Fox, 2018; Esopenko, Simonds, & Anderson, 2018).

The aim of the present study was consequently to investigate whether there is an interaction between age and soccer exposure in their effects on neurocognitive performance. In other words, is playing elite soccer associated with exacerbated cognitive ageing?

## METHOD

This cross-sectional study was conducted as part of two multicentre projects on concussion in soccer. The inclusion criteria for the present analyses were female sex, 15 to 49 years of age, and (previous) participation in elite soccer. Elite soccer was defined as playing in the first league and/or for the national team of Switzerland, Germany, or The Netherlands. Data from active elite female soccer players aged 15–29 years were collected in Switzerland; players were contacted through their soccer clubs and all clubs of the first Swiss league took part in the study. Data from retired elite female soccer players aged 30–49 years were collected in Germany and The Netherlands; contact details of eligible retired players were compiled through records available online and with the help of two well-connected retired female soccer players who acted as study ambassadors. All players who gave written informed consent to participate in the study underwent an initial screening. In participants under 18 years of age, informed consent was obtained from the parents. No player was suffering from a current head injury or symptomatic neurologic/psychiatric disorder; however, individual test results ($n = 9$, .54%) were excluded if at least two of the following three indicators deemed the score invalid: (a) the manufacturers validity indicator (Boyd, 2015), (b) the test administrator at time of testing, (c) scores were outliers ($X_i > Q3$ or $<Q1 \pm 1.5*IQR$). Ethical approval was given by the ethical review boards of Münster, Germany (2016-449-f-S), Kanton Zurich, Switzerland (2017-01921), and the VU University Medical Center Amsterdam, The Netherlands (2017.360).

Relevant demographic and player characteristics were assessed via an online questionnaire and included age, native language, handedness, education, playing position, and concussion history. Concussion was defined as a direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head resulting in specific clinical symptoms that may or may not include loss of consciousness as described by the Concussion in Sports Group (McCrory et al., 2017). Neurocognitive performance was evaluated in the players native language (92.5%) or language of their country of residency (7.5%) using the computerised neuropsychological test battery CNS Vital Signs (CNSVS). This test battery was chosen, as it is one of the core computerised neurocognitive test batteries recommended for the assessment of sport-related concussion (Broglio et al., 2018), and well established for the measurement of subtle cognitive deficits (de Oliveira & Brucki, 2014). There is evidence that CNSVS is sensitive to age-related differences over the lifespan (Gualtieri & Johnson, 2006), able to identify malingerers (Gualtieri & Hervey, 2015), and to discriminate between healthy subjects and patients with various psychological or neurological disorders (Gualtieri & Johnson, 2008; Gualtieri, Johnson, & Benedict, 2006; Iverson, Brooks, Langenecker, & Young, 2011; Meskal, Gehring, van der Linden, Rutten, & Sitskoorn, 2015).

The core test battery is comprised of seven well-established neuropsychological tests, which generate 10 domain scores and 1 composite score (memory; combining visual and verbal memory capacities). Five domain scores and the composite memory score were included in the analysis (Table 1). Excluded domain scores were either considered redundant or were lacking variability (i.e., 96.3% of participants scored ≥38 of 40 points on the continuous performance test). Normative data for the test battery were published by Gualtieri and Johnson (2006) and are based on a sample of healthy male and female US American participants without previous head injury or past neurological disorders.

To assess whether there is an interaction between cognitive ageing and playing soccer, the soccer player sample was split into four age groups (15–19, 20–29, 30–39 and 40–49 years), analogous to the classification of the US norm sample ($n = 585$). All participants in the younger two age groups were still active soccer players, while the older two age groups consisted of retired players. As we did not have access to the original data set of the norm sample, data were simulated based on the published means, *SD*s, and sample sizes per age group. After visual inspection of the domain score distributions in our sample, normal distributions were simulated for all but one domain. Scores for complex attention were simulated assuming a log-normal distribution. All raw domain scores were subsequently standardised and inverted where necessary, resulting in a uniform scale for all domains with a mean of 100, an *SD* of 15, and higher scores reflecting better performance.

All data were processed with SPSS (V.25, IBM) and R (V.3.5.3). Descriptive statistics are presented as means with *SD*s and frequencies with percentage. Mean differences in neurocognitive performance between soccer players and the norm sample by age group were reported with 95% bias corrected and accelerated confidence intervals (CIs) based on 1000 bootstrap samples. To investigate the interaction between cognitive ageing and playing soccer, we used a two-way factorial ANOVA based on 20% trimmed means, due to violation of assumptions related to normality and/or homoscedasticity (Wilcox, 2016). Variables entered into the model were age groups (four groups: 15–19, 20–29, 30–39, 40–49 years), study population (two groups: norm sample vs. soccer players), and interaction terms. As further information on the norm sample was not available, we were

**Table 1.** Description and calculation of domain scores for CNS Vital Signs

| Clinical domain | Test | Domain score calculation | Domain description |
|---|---|---|---|
| Composite memory | VBM, VIM | VBM Correct Hits Immediate + VBM Correct Passes Immediate + VBM Correct Hits Delay + VBM Correct Passes Delay + VIM Correct Hits Immediate + VIM Correct Passes Immediate + VIM Correct Hits Delay + VIM Correct Passes Delay | Ability to remember (retrieve and recognise) words and geometric figures |
| Psychomotor speed | FTT, SDC | FTT Total Taps Average + SDC Correct Responses | Ability to perceive, attend and respond to complex visual-perceptual information, and perform simple fine motor tasks |
| Reaction time | ST | (ST Complex Reaction Time Correct + ST Reaction Time Correct)/2 | Speed of reaction to a simple and increasingly complex set of directions |
| Complex attention | CPT, SAT, ST | ST Errors + SAT Errors + CPT Errors | Ability to track and respond to a variety of stimuli over lengthy periods of time and/or perform complex mental tasks requiring vigilance quickly and accurately |
| Cognitive flexibility | SAT, ST | SAT Correct Responses – SAT Errors – ST Errors | Ability to adapt to a rapidly changing and increasingly complex set of directions and/or to manipulate the information |
| Processing speed | SDC | SDC Correct Responses | Ability to recognise and process information, that is, perceiving/responding to incoming information, motor speed, fine motor coordination, visual-perceptual ability |

*Note:* CPT, Continuous Performance Test; FTT, Finger Tapping Test; SAT, Shifting Attention Test; SDC, Symbol Digit Coding Test; ST, Stroop Test; VBM, Verbal Memory Test; VIM, Visual Memory Test.

not able to adjust the model for potential confounders such as education, sex, or language. Bonferroni correction was used to control the false discovery rate at $\alpha = .05$ ($p < .0083$). Significant interaction effects were followed up with simple effects analysis.

## RESULTS

### Participant Demographics

A total of 240 female soccer players aged 15–49 years took part in the study; 174 active Swiss players, 51 retired German players, and 15 retired Dutch players. Sample size and player characteristics by age group are shown in Tables 2a and 2b. Handedness, native language, and playing position were similar across age groups; the majority of players reported German (77.5%) as their native language, right handedness (91.8%), and midfield (36.7%) or defence (35.4%) as their main playing position. Further, 10% of active (aged 15–29 years) and 3% of retired players (aged 30–49 years) reported a concussion in the last year. Around half of retired players ($n = 32$) had at least one concussion during their lifetime. Differences across age groups were noted in sex distribution of the norm sample and match exposure of soccer players. There were fewer females in the youngest norm sample group, and soccer players aged 40–49 years had the highest match exposure. Additionally, educational attainment varied as a function of age across groups. Overall, the sample was well educated; the vast majority of players aged 20–49 years had obtained a higher secondary degree (58.9%) or above (39.7%).

### Cognitive ageing in female soccer players compared to the norm sample

In the norm sample, cognitive performance generally peaked during the third decade of life and declined thereafter with the exception of complex attention, which showed declines only after the fourth decade of life (Figure 2, supplementary Table S1). Similar, albeit less consistent age trends were observable in the female soccer player sample (Figure 2, supplementary table S1). Soccer players scored higher than the norm sample in all domains and across all age groups with the exception of reaction time (Figure 2, Table 3). The largest mean differences between study populations across age groups were observed in the psychomotor speed domain, with values ranging from 9.80 (95% CI = 4.09, 15.50) in the oldest age group to 16.54 (95% CI = 11.61, 21.47) in the youngest age group (Table 3).

There were no significant interactions between age group and study population in their effects on test performance in the domains memory, psychomotor speed, reaction time, complex attention, and cognitive flexibility (Table 3). However, a significant interaction was found on tests of processing speed ($F = 16.89$, $p = .002$). Simple effects analysis revealed that processing speed scores of soccer players were significantly better than those of the norm sample in the younger two age groups, 15–19 years ($F = 30.06$, $p < .001$) and 20–29 years

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**Table 2a.** Characteristics of elite female soccer players and the norm sample by age group

| Sample | 15–19 years | 20–29 years | 30–39 years | 40–49 years |
|---|---|---|---|---|
| *Sample size* | *n* | *n* | *n* | *n* |
| Elite soccer players | 81 | 93 | 48 | 18 |
| Norm sample | 48 | 153 | 172 | 212 |
| *Age* | *mean (SD)* | *mean (SD)* | *mean (SD)* | *mean (SD)* |
| Elite soccer players | 17.8 (1.1) | 23.0 (2.6) | 35.0 (2.8) | 43.9 (2.4) |
| Norm sample | 16.9 (1.5) | 24.3 (3.1) | 34.9 (2.9) | 44.7 (2.9) |
| *Sex, female* | *% female* | *% female* | *% female* | *% female* |
| Elite soccer players | 100 | 100 | 100 | 100 |
| Norm sample | 43.7 | 68.5 | 63.9 | 66.2 |
| *Handedness, right* | *% right* | *% right* | *% right* | *% right* |
| Elite soccer players | 92.9 | 90.2 | 93.8 | 88.9 |
| Norm sample | 91.7 | 89.5 | 87.0 | 94.1 |
| *Language, German* | *% German* | *% German* | *% German* | *% German* |
| Elite soccer players | 80.2 | 75.3 | 77.1 | 77.8 |
| Norm sample | 0 | 0 | 0 | 0 |
| *Language, English* | *% English* | *% English* | *% English* | *% English* |
| Elite soccer players | 12.3 | 16.1 | 0 | 0 |
| Norm sample | 100 | 100 | 100 | 100 |

*Note:* SD, standard deviation.

**Table 2b.** Characteristics of elite female soccer players by age group

| Elite female soccer players[a] | 15–19 years | 20–29 years | 30–39 years | 40–49 years |
|---|---|---|---|---|
| *Education*[b] | *n (%)* | *n (%)* | *n (%)* | *n (%)* |
| ≤ Primary | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) |
| Lower secondary | 55 (70.5) | 1 (1.2) | 1 (2.1) | 0 (0.0) |
| Higher secondary | 23 (29.5) | 65 (76.5) | 13 (27.1) | 11 (61.1) |
| ≥ Tertiary | 0 (0.0) | 19 (22.4) | 34 (70.8) | 7 (38.9) |
| *Yearly match exposure* | *n (%)* | *n (%)* | *n (%)* | *n (%)* |
| ≥ 45 matches | 6 (7.6) | 8 (9.2) | 5 (10.4) | 5 (27.8) |
| 25–44 matches | 32 (40.5) | 52 (59.8) | 20 (41.7) | 8 (44.4) |
| ≤ 24 matches | 41 (51.9) | 27 (31.0) | 22 (47.9) | 5 (27.8) |
| *Concussion* | *n (%)* | *n (%)* | *n (%)* | *n (%)* |
| 12-month prevalence | 8 (9.9) | 9 (9.9) | 2 (4.3) | 0 (0.0) |
| Lifetime prevalence, 1 concussion | n/a | n/a | 14 (29.2) | 6 (33.3) |
| Lifetime prevalence, ≥2 concussions | n/a | n/a | 10 (20.8) | 3 (16.4) |
| *Playing Position* | *n (%)* | *n (%)* | *n (%)* | *n (%)* |
| Defender | 33 (40.7) | 29 (32.2) | 18 (37.5) | 4 (22.2) |
| Midfielder | 26 (32.1) | 35 (38.9) | 18 (37.5) | 8 (44.4) |
| Attacker | 12 (14.8) | 9 (10.0) | 6 (12.5) | 5 (27 .8) |
| Goalkeeper | 6 (7.4) | 13 (14.4) | 6 (12.5) | 1 (5.6) |
| Multiple | 4 (4.9) | 4 (4.4) | 0 (0.0) | 0 (0.0) |

*Note:* [a]further information on norm sample not available; [b]defintion according to the International Standard Classification of Education (ISCED, 2011 – UNESCO Institute for Statistics, 2012).

($F = 33.25$, $p < .001$), but not in the older two age groups, 30–39 years ($F = 2.69$, $p = .102$) and 40–49 years ($F = 1.43$, $p = .232$).

## DISCUSSION

The aim of the present study was to investigate whether there is an association between playing elite soccer and exacerbated cognitive ageing. This was studied by investigating the interaction between age group and study population (elite soccer players vs. general population) in their effects on neurocognitive performance. We found that cognitive ageing effects were similar in elite soccer players and controls in all but one domain. This is in line with several studies suggesting that participation in elite-level contact sports may not lead to later-life cognitive dysfunction (Deshpande et al., 2017; Willer et al., 2018). Significant interactions were only observed in the domain processing speed, where soccer

**Table 3.** Mean differences in neurocognitive performance between soccer players and the norm sample by age group and interaction effects

| | 15–19 years | | 20–29 years | | 30–39 years | | 40–49 years | | Interaction | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *MD*[a] | *95% CI*[b] | *MD*[a] | *95% CI*[b] | *MD*[a] | *95% CI*[b] | *MD*[a] | *95% CI*[b] | *F* | *p* |
| Composite memory | 6.79 | 1.95, 11.62 | 2.48 | −1.30, 6.26 | 6.23 | 1.46, 10.99 | 3.60 | −2.89, 10.09 | 1.71 | .645 |
| Psychomotor speed | 16.54 | 11.61, 21.47 | 12.39 | 9.17, 15.61 | 11.79 | 8.13, 15.46 | 9.80 | 4.09, 15.50 | 4.84 | .201 |
| Reaction time | 3.90 | −1.16, 8.96 | −5.66 | −9.00, −2.32 | −1.96 | −6.06, 2.14 | −.10 | −6.32, 6.12 | 10.10 | .026 |
| Complex attention | 3.27 | −.71, 7.25 | 1.32 | −2.31, 4.95 | 2.37 | −1.85, 6.58 | 7.60 | 2.38, 12.83 | 5.69 | .144 |
| Cognitive flexibility | 6.57 | 2.31, 10.83 | 1.34 | −2.00, 4.67 | 4.11 | −.80, 9.02 | 5.68 | −.18, 11.54 | 5.04 | .185 |
| Processing speed | 13.40 | 7.85, 18.95 | 10.21 | 6.58, 13.84 | 4.04 | .34, 7.74 | 3.88 | −.56, 8.32 | 16.89 | .002* |

*Note:* MD, mean difference; CI, confidence interval; [a]reference group: norm sample; [b]bias corrected and accelerated based on 1000 bootstrap samples; *$p < .0083$.

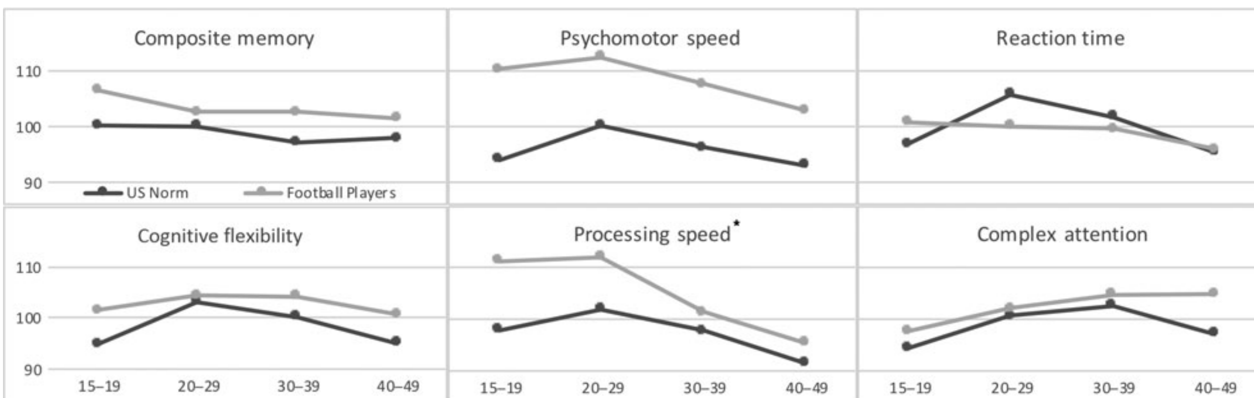


**Fig. 2.** Neurocognitive performance in elite soccer players and the norm sample; note that lines are a visual aid and do not represent data points; *significant interaction effect.

players outperformed the norm in the younger two age groups, but not in the older two age groups. As processing speed is highly sensitive to both the effects of cognitive ageing and brain injury (Salthouse, 2010; Tarnutzer et al., 2017), this finding does fit the initial hypothesis well. However, as this effect could only be observed in one out of six domains, we gather that our data do not support the exacerbated decline hypothesis at this point.

It should be noted, however, that given the limitations of this study drawing any firm conclusions would be premature. Particularly, the chosen age range prevents inferences about age trends in soccer players beyond middle age. While age-related cognitive decline of fluid abilities is generally evident from early adulthood onwards, there is great interindividual variability regarding the onset and rate of decline (Moretti et al., 2012). In the norm sample, age trends were very consistent and in line with the findings from large-scale studies (Salthouse, 2010), while less consistent age effects were observed in the soccer player sample. It may be that in elite soccer, age-related cognitive decline, and thus, the proposed exacerbation due to RSHI or concussion, only becomes apparent later in life; especially, considering that lifestyle factors such as regular physical activity are believed to positively correlate with cognitive reserve. The cognitive reserve theory maintains that individuals with high cognitive reserve have more robust neuronal networks. Due to either compensatory or neuroprotective mechanisms, this may delay age-related cognitive decline and mitigate the impact of brain damage/pathology on clinical outcomes (Stern, 2009). Hence, the suspected cumulative effect of previous head impacts and age-related cognitive decline may have been compensated by cognitive reserve in players up to middle age.

Another noteworthy result of this study is the effect of study population on neurocognitive performance. The youngest age group of elite female soccer players performed better in all test domains when compared to age-matched controls. The greatest mean differences in this age group were found in domains related to processing speed and motor speed tasks. This is in line with the literature, suggesting sport-context-specific (Mann, Williams, Ward, & Janelle, 2007), and general cognitive enhancements through sports. In soccer and other strategic sports, a positive relationship between abilities underlying higher executive functioning and on pitch performance has been reported by several recent studies (Huijgen et al., 2015). The superior performance of young elite soccer players may be explained through the rich and cognitively stimulating environment of elite sports in combination with the positive effects of physical activity (Voss, Kramer, Basak, Prakash, & Roberts, 2010). In light of the focus on adverse outcomes, it is important to note that

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contact sport also seems to have inherent beneficial effects on cognitive performance. Of course, self-selection effects cannot be ruled out, as players with better executive functioning may have a higher likelihood to be selected for an elite-level team.

The trend of soccer players outperforming the norm sample is maintained across all age groups and domains with the exception of reaction time. Reaction time was the only domain, in which soccer players performed worse than the norm sample (age groups 20–29 and 30–39 years). However, it is unlikely that this is an effect of exposure to RSHI or concussion, as similar results were reported by Hume et al. (2017), who found retired rugby players with and without previous concussions as well as non-contact sport athletes to have significantly worse reaction time scores compared to the US norm. This is surprising since rapid information processing and inhibitory control are skills frequently required and trained in the team sport environment.

Our study has several limitations. First, only very limited information was available on the norm sample, and therefore, we cannot rule out that the norm sample included participants that have been exposed to RSHI during their lives. Additionally, we were not able to adequately match the study groups on relevant socio-demographic factors such as sex, education, and native language. However, since age trends in cognitive performance were our primary interest, socio-demographic differences between age groups, not study groups, are the main concern. Language, sex, and several other relevant variables were assessed and found to be similarly distributed across age groups. Thus, while the lack of adequate matching is a significant concern for the interpretation of main effects, we do not expect language or sex to have a differential effect on cognitive ageing in our relatively young sample. This notion is corroborated by a previous study with male and female soccer players aged 15–30 years; when stratifying the sample by sex, age effects were found to persist (Prien, Junge, Brugger, Straumann, & Feddermann-Demont, 2019). However, no information on educational attainment was available for the norm sample, and therefore, education-related cohort biases cannot be ruled out. It is also noteworthy that fewer soccer players aged 40–49 years had a tertiary degree than players aged 30–39 years. Another source of potential cohort bias is the overlap of age groups with player status (active/retired) and country of residency; while all active players (aged 19–29 years) were from Switzerland, all retired players (aged 30–49 years) were from Germany or The Netherlands. Further, it could be argued that any interaction effects may only be apparent in previously concussed soccer players and are masked by the majority of non-concussed athletes included in the study. However, this is unlikely as lifetime concussion prevalence in the two older age groups was high (50%) and 10% of soccer players in the younger age groups reported a concussion in the previous year alone. Finally, recruitment for the eldest age group fell short, and thus, results for this age group must be interpreted more carefully.

The findings of the present study hold key information for meaningful future research on the topic of cognitive ageing in contact sport athletes. First, cross-sectional studies investigating the potential long-term effect of RSHI or concussion on cognitive performance in contact sport athletes should focus on age groups older than 50 years, as clinically observable differences seem unlikely in younger age groups. Second, as elite athletes generally perform better on neurocognitive tests than the normal population, it is important to choose an adequate control group (e.g., elite athletes from non-contact sports). Third, when conducting research on neurocognitive performance across the lifespan, it would be desirable to control for variables related to cognitive reserve. Recommended proxies for cognitive reserve in elite athletes are (childhood) IQ, literacy, or composite measures (Stern, 2012). While educational attainment is one of the most commonly used proxies, it is not a valid measure when investigating groups under 25 years of age.

## CONCLUSION

While there was a clear trend in the effect of study population on neurocognitive performance, ageing effects were similar in soccer players and controls. Female soccer players generally performed better on tests of cognitive function compared to the norm; however, evidence did not support an overall exacerbated cognitive ageing process. This is the first study using a lifespan approach to research neurocognitive performance in contact sport athletes, and we believe that this approach may hold promise for insightful research in the future.

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## CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest to disclose.

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## SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/S1355617720000119.

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