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ABSTRACT

Assessing heading exposure in football is important when exploring the association between heading and brain alterations. To this end, questionnaires have been developed for use in adult populations. However, the validity of self-report in adolescents remains to be elucidated. Male youth soccer players (n = 34) completed a questionnaire on heading exposure after a two-week period, which included matches and training sessions. Self-reported numbers were compared to observation (considered reference). In total, we observed 157 training sessions and 64 matches. Self-reported heading exposure correlated with observed heading exposure (Spearman's rho 0.68; p < 0.001). Players systematically overestimated their heading exposure by a factor of 3 with the random error of 46%. Area under the curve was 0.87 (95% CI 0.67–1) utilizing self-report for identifying players from high- and low-exposure groups. Thus, in this study, self-reported data could be used to group youth players into high and low heading exposure groups, but not to quantify individual heading exposure.

Introduction

Recent studies suggest there may be neurological consequences from head impact exposure in contact sports such as American football, boxing and ice hockey (Asken et al., 2017; Mez et al., 2020, 2017). In soccer, even though an increased risk of neurodegenerative disorders in later life has been found (Mackay et al., 2019), it has not yet been

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established whether or not heading the ball is the cause of harm to the brain (Kontos et al., 2017; Tarnutzer et al., 2017). However, preliminary studies using advanced neuroimaging techniques have implied that heading the ball may cause structural alterations in the brain (Koerte et al., 2012, 2015, 2016; Lipton et al., 2013). Moreover, recent evidence also suggests that heading may impair cognitive function in both adults (Lipton et al., 2013; Stewart et al., 2018) and adolescents (Koerte et al., 2017; Zhang et al., 2013). With hundreds of millions of active players worldwide, any short- or long-term neurological consequences could have a considerable public health impact.

A methodological limitation in previous studies has been inadequate quantification of heading exposure (e.g. see review by (Tarnutzer et al., 2017)); this relates to single sessions as well as longer periods. Ideally, data are needed not only on the number of headers for each player but also on the biomechanical characteristics of each impact (Broglio et al., 2017). In theory, wearable sensor systems have the potential to achieve this (Brennan et al., 2017; O'Connor et al., 2017; Patton, 2016). However, previous studies have demonstrated that sensors are impractical for large-scale studies (Press & Rowson, 2017; Sandmo et al., 2019). Specifically, inaccurate sensor outputs and failure to adequately filter out false-positive events constitute central impediments (Cortes et al., 2017; Press & Rowson, 2017; Sandmo et al., 2019). Alternative methods, such as direct observation or video analysis, can provide objective information on the number of head impacts, but not readily on their magnitudes (Krosshaug et al., 2005; Sandmo et al., 2019). Regardless, such methods are resource demanding as they require either the continuous presence of research personnel or time-consuming post-session analysis of video recordings.

Self-report allows for low-cost and easy administration, and therefore remains a favourable alternative for quantifying head impact exposure in large-scale cohort studies. Importantly, self-reported heading exposure has been associated with structural brain alterations (Koerte et al., 2015, 2016; Lipton et al., 2013) as well as neurological symptoms (Stewart et al., 2017) and cognitive performance (Lipton et al., 2013; Stewart et al., 2018). Previous studies have described how self-reported head impact exposure can be used in adult populations (Catenaccio et al., 2016; Lipton et al., 2017; Montenigro et al., 2017). Specifically, Catenaccio et al. (2016) described the external validation of a two-week recall questionnaire in adult soccer. However, it is unknown how reliable this approach is among youth players. Thus, the aim of this study was to test the validity of a questionnaire (Catenaccio et al., 2016) for quantifying heading exposure in male youth soccer players over a two-week period.

Methods

Study design and participants

Male elite youth soccer players from three different European countries [Norway, Germany and Belgium] were invited to participate in the study during the 2018 season. Players from Norway were part of the study RepImpact (www.repimpact.org); players from Germany and Belgium were recruited solely for the purposes of the current study. Recruitment was done through coaches and supporting staff of local teams that invited their respective team members to participate voluntarily. Table 1 shows the characteristics of the participants.

The study was approved by the Regional Committee for Medical and Health Research Ethics South East, Norway; the Ethics Committee of the Medical Faculty at the University of

Table 1. Descriptive characteristics of the participants.

Characteristic	Belgium	Germany	Norway	Total
N	8	14	12	34
Age (mean ± SD)	14.2 ± 0.3	14.3 ± 0.4	15.4 ± 0.6	14.7 ± 0.7
Playing positions (N)				
Goalkeeper	0	2	0	2 (6%)
Central defender	1	3	3	7 (21%)
Fullback/wingback	1	3	2	6 (18%)
Central/inside midfielder	3	1	2	6 (18%)
Wing/offensive midfielder	3	1	4	8 (23%)
Striker	0	4	1	5 (15%)

Munich, Germany; and the local Ethics Committee of UZ/KU Leuven, Belgium. Written informed consent was obtained from the participants and their legal guardians.

Observed heading exposure

For two weeks, trained research personnel attended all training sessions and matches of the participating teams. During this period, all heading exposure for each player in each session was registered, using either (1) direct observation or (2) video recordings. Specifically, direct observation was used for both training sessions and matches in Germany and Belgium. For each training session, two to eight observers were present; each observer was assigned to specific players, with a maximum of seven players per observer. For each match, one to four observers were present; each observer was instructed to follow the ball, and any discrepancies were resolved by consensus. In Norway, direct observation was used for matches, while video recordings with subsequent structured video analysis were used for training sessions. Video recordings were obtained with three digital video cameras (1080p, 50 fps), placed to capture all players for the entirety of the training sessions.

A heading event was defined as any incident where a player intentionally headed the ball. Regardless of the perceived magnitude, any such event was registered and assigned to each individual player as one header. Observed heading exposure was subsequently used as reference. Accidental/unintentional head impacts were also registered if observed, but were not included in the analyses, as they were outside the scope of the study.

Self-reported heading exposure

On the last day of the observation period, all 34 participants completed a questionnaire in their native language, retrospectively quantifying their heading and playing exposure during the study period. Participants in Norway completed the questionnaire digitally, receiving a link to the form via SMS; participants in Germany and Belgium used pen and paper.

The questionnaire was based on a previously validated method for adult populations (Catenaccio et al., 2016; Lipton et al., 2017); a detailed account of its contents has been published elsewhere (Catenaccio et al., 2016; Lipton et al., 2013). In short, the respondents were asked to quantify their absolute number of training sessions and matches at the end of a two-week period, as well as the average number of headings for each of these two

session types (see supplemental material for a full copy of the questionnaire that was used).

The participants were not blinded to the aims or outcome measures of the study, as prior consent was needed. Furthermore, at the start of the study period and when completing the questionnaire, they were specifically instructed to only include heading exposure during organized training sessions and matches with their primary team (i.e. the team that was observed in the study); thus, they were told to disregard other sessions, e.g., with soccer academies and regional/national teams.

Data analyses

Self-reported heading exposure for each participant over the two-week period was calculated by (1) multiplying the reported average number of headers in training with the reported number of training sessions, and (2) multiplying the reported average number of headers in matches with the reported number of matches. These were summed to represent total heading exposure (Catenaccio et al., 2016; Lipton et al., 2017). Self-reported heading exposure in matches, self-reported heading exposure in training and total self-reported heading exposure were compared to the observed number of headers (i.e. the reference).

Heading exposure scores were non-normally distributed, similarly to previous studies (Stewart et al., 2017). Thus, Spearman's rank correlation coefficient was used to evaluate the association between self-reported and observed heading exposure (i.e. the reference). This was done separately for training sessions and matches, as well as for all sessions combined. In the same way, we also explored associations between other self-reported and observed exposure variables (e.g. the number of matches). To estimate the accuracy and precision of self-reported heading exposure, we calculated its systematic and random error. Systematic error was calculated as the difference between median self-reported and observed heading exposure. This difference was expressed as a factor based on observed heading exposure, with corresponding interquartile ranges (IQR); positive (negative) results indicate overestimation (underestimation) of self-reported heading exposure, and factors are directly translatable to percentages. Random error was expressed as the coefficient of variation (CV), and was calculated in two steps: First, the method error (ME) was calculated by dividing the standard deviation (SD) of the mean difference between self-reported and observed heading exposure by the square root of the number of measurements:

$$ME = SD_{mean\ difference}/\sqrt{2}$$

Second, the method error was divided by the mean of the combined measurements:

$$CV = ME/(mean_{self\ report} + mean_{observed}/2)$$

Random error is expressed as a percentage; greater values represent more variation and thereby poorer precision (Sale, 1991).

We also conducted receiver operating characteristic (ROC) analyses to evaluate the ability of self-reported data to identify players belonging to high and low-exposure groups. For defining the exposure groups, we randomly and equally split our dataset into two groups: a training (n = 17) and a validation dataset (n = 17). Then, based on either (1) the median or (2) the tertiles of the observed heading exposure in the training dataset,

we categorized players in the validation dataset into groups of high and low levels of exposure. The ROC analyses were performed on the validation dataset, using the self-reported scores.

All statistical analyses were performed using SAS (version 9.4; SAS Institute Inc., North Carolina, USA), and an alpha level of 0.05 was used to denote statistical significance.

Results

For all 34 participants combined, we observed a total of 157 training sessions and 64 matches during the two-week study period. In total, we observed 1 051 headers; 928 headers (88%) occurred during training, and 123 headers (12%) occurred during matches. Table 2 shows how training sessions, matches and heading exposure were distributed for players from different countries.

As shown in Table 2, players tended to overestimate their heading exposure compared to the numbers observed. Evaluating the systematic error, the players overestimated total heading exposure by a factor of 3.0 (IQR = 4.8); the corresponding random error was 46%. In training sessions, the overestimation was by a factor of 3.7 (IQR = 6.3), with a random error of 49%. In matches, the overestimation was by a factor of 0.5 (IQR = 1.4), with a random error of 44%.

For self-reported and observed total heading exposure during the study period, the Spearman's rank correlation coefficient was 0.68 (p < 0.001) (Figure 1(a)). For training sessions, the correlation was 0.67 (p < 0.001) (Figure 1(b)); for matches, the correlation was 0.73 (p < 0.001) (Figure 1(c)).

For the ROC-analyses, the median observed exposure in the training dataset was 36; using this cut-off in the validation dataset, 4 players belonged to the high-exposure group and 13 players to the low-exposure group. The area under the curve (AUC) was 0.87 (95% CI 0.67–1) for using the self-reported scores to identify the two groups. Based on the tertiles (low<22, high>54), the validation dataset had three players in the high-exposure group and nine players in the low-exposure group, for which the AUC for using the self-reported scores increased to 0.96 (95% CI 0.86–1).

When exploring correlations between other self-reported and observed exposures, we detected several significant associations (Table 3). Exempting total headers in matches, the greatest numerical correlation was seen between self-reported and observed number of matches (0.70; p < 0.001).

Discussion

This study evaluated the validity of using a questionnaire to assess heading exposure over a two-week period in male youth soccer players. Self-reported data displayed a marked systematic overestimation of heading exposure in combination with considerable random error (Figure 1), suggesting low accuracy and precision. Nevertheless, there was a 0.68 correlation coefficient (Spearman's rho) between total self-reported and observed heading exposure (i.e. in matches and training sessions combined), indicating a moderate ability (Akoglu, 2018) of self-report to capture the rank order of heading exposure between players. Also, as shown by the ROC analyses, the accuracy of self-report to categorize players into groups of different exposure levels (e.g. high vs. low) was high.

Table 2. Observed vs. self-reported heading exposure for youth soccer players during a two-week period.

	Belgium		Germany		Norway		All sites combined	
	Observed	Self-reported	Observed	Self-reported	Observed	Self-reported	Observed	Self-reported
Total headers in matches	3.0 (6.5)	5.5 (4.8)	2.0 (2.0)	2.5 (10.0)	4.5 (3.0)	8.3 (9.5)	3.0 (4.0)	5.0 (8.5)
Total headers in training sessions	3.5 (6.0)	29.5 (43.0)	36.0 (27.0)	131.5 (180.0)	22.0 (49.0)	47.5 (90.6)	22.0 (42.0)	65.0 (125.0)
Number of matches	2.0 (1.0)	1.5 (2.0)	2.5 (2.0)	2.0 (1.0)	2.0 (1.0)	1.5 (2.0)	2.0 (2.0)	2.0 (2.0)
Number of training sessions	6.5 (3.0)	8.0 (0.5)	4.5 (2.0)	5.0 (2.0)	4.5 (1.5)	5.0 (2.3)	5.0 (1.0)	5.8 (2.0)
Headers per match	2.0 (3.3)	4.0 (3.3)	1.0 (1.5)	2.5 (3.0)	2.0 (2.9)	3.0 (4.0)	1.6 (1.8)	3.0 (3.0)
Headers per training session	0.7 (0.7)	4.0 (3.5)	9.0 (3.8)	27.5 (30.0)	7.4 (9.3)	13.8 (11.3)	7.3 (9.2)	13.8 (25.0)

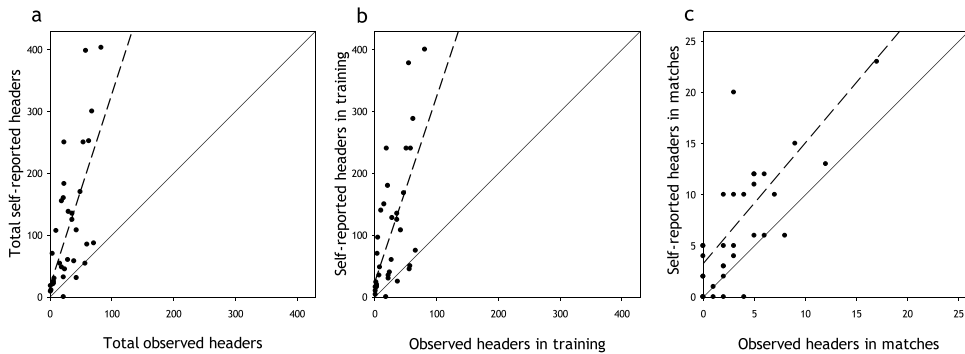Numbers are presented as median (interquartile range).

Figure 1. Self-reported heading exposure from (a) all sessions combined, (b) training sessions only and (c) matches only, over a two-week period, plotted against observed exposure. Solid lines are for reference, dashed lines indicate the line of best fit.

Taken together, these findings suggest that self-reported heading exposure have the potential to rank or group players on a population level.

With ongoing studies evaluating the potential effects of heading in youth soccer, developing adequate measures for quantifying exposure is key to assess outcomes (Tarnutzer et al., 2017). We, therefore, set out to assess the utility of self-reported heading exposure in youth players, using a previously validated method (Catenaccio et al., 2016). Catenaccio et al. (2016) evaluated the ability of a two-week recall questionnaire to measure match-related heading exposure in male and female collegiate soccer players. Based on their findings, they concluded that self-report is a valid and reliable instrument for tracking heading exposure in population studies, but noted that it might have to be calibrated in women. Specifically, they described a slight underestimation in men (requiring little to no adjustment) and a marked overestimation in women (factor of 5). Comparing our match-related results to those of male senior players from Catenaccio et al. (2016), both studies found a similar positive correlation between self-reported and observed heading exposure in matches (Spearman's rho of 0.73 in our study vs. a range of 0.75–0.95 in theirs, looking at multiple two-week periods). Nevertheless, we found that youth players systematically overestimated their exposure (factor of 0.5 in matches); in contrast, Catenaccio et al. (2016) found that male collegiate players systematically underestimated theirs, but only slightly.

We note that our observation of a systematic overestimation in youth players is in accordance with a recent study by Harriss et al. (2018). They evaluated the ability of female youth players (age 13 years) to recall their match-related heading exposure over an entire season, and found that the players overestimated heading frequency by 51% compared to video observation; this is comparable to our reported systematic overestimation in matches by a factor of 0.5. As they evaluated a cohort of female players, this suggests that youth players tend to overestimate regardless of sex. Harriss et al. (2018) went on to emphasize the need to take recall bias into account when using self-report. Their conclusion, however, was based on a considerably longer recall period (i.e. a whole season) compared to our capturing a two-week interval. In summary, based on these two studies (Catenaccio et al., 2016; Harriss et al., 2018) and ours, age and sex warrant careful consideration when using self-report to estimate heading exposure.

Table 3. Correlations between self-reported and observed exposures from two weeks of participation in youth soccer. Top numbers display the Spearman's rank correlation coefficient, and lower numbers denote the corresponding p-value.

		Observed				
		Total headers in matches	Total headers in training sessions	Headers permatch	Headers pertraining session	Number of matches	Number of training sessions
Self-reported	Total headers in matches	0.73 <.0001					
	Total headers in training sessions		0.67 <.0001				
	Headers per match			0.52 <.01			
	Headers per training session				0.61 <.001		
	Number of matches					0.70 <.0001	
	Number of training sessions						0.63 <.0001

Ideally, one could adjust for a systematic overestimation. However, there was also substantial random error (46% overall) in our data, indicating poor precision. Thus, combining the systematic and random error, the value of using self-report to measure the absolute number of headers for an individual player becomes limited. Furthermore, systematic and random error might vary between session types. Of note, previous studies (Catenaccio et al., 2016; Harriss et al., 2018) were solely based on match exposure. In our data, we observed that the total self-reported systematic overestimation was mainly driven by poor accuracy in training-related exposure (factor of 3.7 versus 0.5 in matches).

We can only speculate as to why self-report in adolescents is inaccurate to such an extent. A previous study by Rutherford and Fernie (2005) pointed out that heading the ball can be regarded as an everyday event for active soccer players. They hypothesized that self-reported estimates of such daily events are likely to be governed by specific psychological mechanisms, such as rule-based estimation strategies; such strategies typically lead to overestimations (Thompson & Mingay, 1991). As shown in Table 3, we also explored relationships between other self-reported and observed variables. This allowed us to obtain a broader view of the general validity of self-report in a youth population. Interestingly, many of the participants not only overestimated their average heading exposure per session but also reported inaccurate numbers for matches and training sessions. Previous research on self-reported physical activity has pointed out the limited ability for children to perform abstract reasoning and detailed recalls (Sallis, 1991). Based on our experience, we also find it reasonable to suspect that it can vary how interested and devoted adolescents are when completing any such questionnaire. Furthermore, future studies should explore how variation in factors such as observation periods; session types; playing styles; impact characteristics; between-session variability in the number of headers; and questionnaire structure might affect the validity of self-reported heading exposure.

Despite the challenges concerning systematic and random error, our results indicate that self-report might still be an appropriate method for quantifying heading exposure in youth soccer. First, the method seems to retain an acceptable ability to rank players with respect to exposure levels, as illustrated by the correlation coefficient (0.68 across all sessions). We interpret this as being facilitated by Spearman's rho as a statistical method; specifically, as the numbers are converted to rank orders across the sample, it remains unaffected by extreme values. Second, as demonstrated by the ROC-analyses, self-reported heading exposures displayed the ability to correctly categorize players into different exposure groups (e.g. high and low). In other words, players with relatively higher levels of heading exposure tended to report numbers that would classify them correctly as belonging to a high-exposure group. As expected, accuracy improved when comparing more extreme ends of the high vs. low-exposure spectrum. This is demonstrated by the AUC increase from 0.87 to 0.96 when applying it to identify the group with the greatest heading exposure. Summarizing these findings, our data show that self-report seems adequate to rank or group youth players with respect to heading exposure. This aligns with previous findings in adult populations (Catenaccio et al., 2016; Lipton et al., 2013).

As an interesting additional finding in our study, based on our observed data, we describe how total heading exposure in this cohort mainly originated from training sessions (88%). Importantly, while match-related heading exposure was recently characterized in detail (Sandmo et al., 2020), such objective data on training-related exposure have been scarce. However, we note that this difference seemed to be greater in Germany

and Norway than in Belgium (Table 2). Despite low sample sizes when comparing between sites, this suggests that factors such as playing styles and coaching philosophies have an influence. Such factors should be explored in future studies.

We recognize several methodological considerations. First, using direct observation as reference has its own limitations. For matches, a recent study demonstrated that having one sideline observer yielded a sensitivity of 91% for identifying headers, with an inter-rater reliability of 0.99 (Sandmo et al., 2020). However, whether this translates to training sessions is not known. Of note, training sessions are highly variable with respect to drills and exercises and may therefore become more chaotic than matches (e.g. by having more than one ball in play at the same time). We, therefore, strived to have one observer per player during training sessions, which, however, was not possible for all sessions. With one observer sometimes having to account for more than one player at a time (maximum of seven), this might have negatively affected the sensitivity of a subset of the observations. Second, both observed and self-reported heading exposure quantify the number of impacts only. Consequently, it was not possible to account for variations in impact magnitudes (i.e. linear and rotational accelerations); this has previously been shown to vary according to factors such as head and neck size (Caccese et al., 2017), as well as session and heading types (Caccese et al., 2016; Sandmo et al., 2019). As an example, we note that some participants would sometimes juggle the ball on their head during training, which could lead to a high number of what is likely to be low-magnitude impacts. Third, our sample size is limited; even if the players were recruited from three different countries, applying our findings to other samples and populations (e.g. girls) should be done with care. Fourth, for logistical reasons, we were able to observe players on their primary team only. As a result, the observed heading exposure is almost certainly an underestimation of the total two-week exposure for some of the participants. Playing on a high level, some players had other sessions as part of soccer academies and regional/national teams. While we specifically instructed players to only include exposure related to their primary team, this could have been confusing and consequently a source of bias; importantly, this might have contributed to the overestimation when completing the questionnaire. Last, the participants knew they were being observed throughout the study period. We do not know if this may have led to changes in behaviour or to more accurate reports than would otherwise be expected. In summary, however, it is unlikely that these limitations undermine our main findings. Instead, they highlight important aspects that make head impact quantification in contact sports challenging.

In conclusion, this study demonstrates the need for careful interpretation when using self-reported data to quantify heading exposure in male youth soccer. Due to substantial systematic and random error, self-report should not be used for determining individual absolute heading exposures. It may, however, serve as a potential tool to rank or group players with respect to heading exposure.

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Disclosure statement

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