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Symptoms after sport-related concussions alter gestural functions

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ABSTRACT

Objectives: Symptoms after sport-related concussions (SRC) are common. Because post-concussion symptoms are often not clearly visible, speech-accompanying gestures may help clinicians to gain additional information about the patient's history and symptoms during medical consultation. We hypothesized that athletes with SRC and who suffered from persisting symptoms would display more gestures during concussion assessment protocols when compared to non-concussed athletes because of the athletes' previous motor-sensory experiences made during the concussive event.
Design: A retrospective cross-sectional study.
Methods: Three matched groups of 40 (active) athletes were investigated in the context of concussion assessment (/and baseline) protocols: 14 symptomatic and 14 asymptomatic athletes with a SRC, and 12 non-concussed athletes. Certified raters using a standard analysis system for nonverbal behaviour analysed videotaped hand movements and gestures during a standardized concussion assessment protocol.
Results: Symptomatic athletes spent significantly more time with *in space* hand movements, i.e., movements that act in the body-external free space without touching anything and specifically, *motion quality presentation* gestures than non-concussed athletes.
Conclusions: Increased *in space* movements, which are functionally gestures, and specifically, *motion quality presentation* gestures in symptomatic athletes indicate that the more vivid sensory motor experience of the head trauma is reflected in more gestural expressions. Thus, hand movements and gestures differentiate athletes who suffer from post-concussion symptoms from non-concussed athletes indicating the athletes' motor-sensory experiences of the event and its aftereffects. The present study highlights the fact that gestures can be employed as behavioural markers of symptoms after sport-related concussions.

Practical implications

- Nonverbal hand movement behaviour serves as a potential behavioural marker of post-concussion symptoms.
- Athletes who suffer from symptoms after sport-related concussions show altered hand movement and gestural behaviour.
- Increased *in space* hand movements and *motion quality presentation* gestures in symptomatic athletes indicate the athletes' vivid sensory motor experience of the concussive event.

1. Introduction

The medical evaluation of mild traumatic brain injuries (mTBI) in sports (/sport-related concussions (SRC)) remains difficult as symptoms of a concussion are diverse and often not clearly visible.[1] A particular problem when self-reporting symptoms constitutes communication between an athlete and the medical personnel as patients who describe symptoms often encounter difficulties in their verbal expressions, particularly when individuals (and the listener) have never experienced particular symptoms before.[2] Standardized protocols have been developed for medical professionals to evaluate an athlete's health status by query multiple aspects of potential post-concussion symptoms.[1] However, such tools constrain the description to a limited number of predetermined categories and descriptors that may not capture all aspects of the actual experience.[3] Because the nonverbal communication has been described as essential for successful patient-practitioner interactions,[4,5] the present investigation addresses for the first time nonverbal hand movements and gestures of athletes with sport-related concussions during concussion assessment protocols.

Speech-accompanying gestures (i.e., spontaneous movements of the hands, arms and other body parts that are closely synchronized with speech[6]) constitute a form of nonverbal communication that may help to gain additional information when evaluat-

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ing symptoms during medical consultation.[6–8] Previous research showed that speech-accompanying gestures in communication about clinical symptoms depict information about pain, including sensation, location, size, and cause.[6,10,11] In fact, recipients are able to pick up additional information from gestures that accompany another person's pain descriptions when compared to information that is solely transferred via speech without gestures.[8] Thus, speech-accompanying gestures of athletes with mTBI in sports might contain particular nonverbal information that is not present in athletes who do not suffer from post-concussion symptoms. However, thus far, speech-accompanying gestures have not been systematically investigated after SRC.

Speech-accompanying gestures during human communication constitute a reliable source of information about visuo-sensory-motor experiences as speakers who describe previously performed actions use particular gestural depictions of movement and space during the explanation of those actions.[12,13] Hostetter and Alibali argue that gestures emerge from motor simulations that underlie mental imagery.[13] Lausberg[14] further proposes that sensory experiences (e.g. how something feels like) are transformed specifically into *motion quality presentation* gestures when reporting about these experiences. Because sport-related concussions are characterized either by a direct blow to the head, face, neck or elsewhere on the body with an "impulsive' force transmitted to the head,[1] i.e. events that necessitate visuo-sensory-motor imagery when being asked to describe, speech-accompanying gestures must reveal particular information about aspects of movement and space. Furthermore, motor-related brain cortices are increasingly activated with previous motor-sensory experiences of an individual.[15] Thus, athletes who experienced SRC are more likely to provide gestural descriptions of concussive events based on their motor-sensory experiences of the event, which does apply to athletes who did not experience concussions before. We therefore hypothesize that athletes with mTBI and ongoing post-concussion symptoms increase their gestural output to provide additional information to their descriptions during concussion assessment protocols.

2. Materials and methods

40 adult/junior non-professional athletes (mean age: 22.7 ± 4.5; 13 female, 27 male; 35 right-handers, 4 left-handers, 1 ambidextrous; average years of sports participation: 9.2 ± 5.8) from various sports (American Football (N = 13), hockey (N = 8), boxing (N = 5), rugby (N = 4), etc.) participated in the (retrospective) study as part of a concussion assessment and baseline protocol. Participants were recruited via cooperation of the German Sports University (GSU) with local sports-clubs with the inclusion criteria such as: active sports participation in (contact) sports (meaning that athletes were participating in training and competitions (e.g., 2nd or 3rd German football league) on a weekly basis), and with or without (baseline testing) the history of a concussion. Written informed consent was obtained from each participant. The local Ethics Committee of the GSU approved the study.

Concussed athletes (N = 28; mean age: 23.5 ± 4.7; 8 female, 20 male) included athletes with self-reported post-concussion symptoms (N = 14) and without (/asymptomatic) symptoms (N = 14) at variant time-points post-concussion. The two concussed participant groups were matched according to their age, time post-concussion, and the amount of experienced concussions (i.e., there were no significant differences (mean time post-concussion = 22.0 ± 46.5 months; mean amount of experienced concussions = 1.8 ± 0.9)). Non-concussed athletes were matched in age, gender, years of sports participation, and years of education with the two concussed groups (N = 12, mean age: 20.6 ± 3.4; 5 female, 7 male) and served as a control group in this retrospective cross-sectional study.

Concussions were assessed using self-reports according to the definition of the consensus statement on concussion in sport.[16] The symptom assessment scale of the "Sport Concussion Assessment Tool – 3rd edition" (SCAT3)[17] was used to collect participants post-concussive symptoms. In this Likert-like symptom scale, each symptom is rated from 0 ("none") to 6 ("severe"). The number of 22 symptoms is summated to a post-concussion symptom score (PCS score) with a maximum of 132 (22×6). We used a PCS score of 10 as a cut-off to differentiate between symptomatic and asymptomatic (concussed) athletes in line with previous studies.[18–20] Symptomatic athletes present significantly higher PCS scores ($F(2, 37) = 36.507$, $p < 0.001$; (mean) PCS = 30.0 ± 15.0) when compared to asymptomatic ($p < 0.001$; PCS = 3.7 ± 3.3) and non-concussed athletes ($p < 0.001$; PCS = 3.7 ± 3.3).

In the first part of the interview ('concussive incident'), participants were questioned using a standardized questionnaire about the occurrence of a mild traumatic brain injury (if it applied), description of the incident (if the participants had not experienced a concussion her-himself, she/he was asked to describe a concussion that she/he had observed in others), and the time post-concussion (if it applied). In the second part of the interview ('symptoms report'), participants were interviewed regarding the presence or absence of post-concussive symptoms according to the symptom scale used in the "Sport Concussion Assessment Tool – 3rd edition" (SCAT3).[17] The interview was recorded using a digital video camera (Canon Powershot G10) placed 3 m in front of the interviewee (Fig. 1).

All occurring hand movements and gestures were coded using the NEUROGES® (NEUROpsychological GESture) analysis system for nonverbal behaviour.[14,21] Among the existent coding systems for hand movements, the NEUROGES has been chosen as it is objective and reliable.[23] The present research focused on the analysis of the Focus and Function category of the NEUROGES system. The Focus category refers to the presence or absence of dynamic contact with something/someone that the hand acts on. Six Focus values are distinguished: *within body*, *on body*, *on attached object*, *on separate object*, *on person*, and *in space*. The Focus values reflect the locus of attention and sensory feedback including the functional distinction between self-touch and gesture. In order to gain insights into the gestural functions of an individual, NEUROGES offers the analysis of gesture types according to their function (of the right, left, and both hands). 11 Function values are distinguished: *emotion/attitude*, *emphasis*, *egocentric deictic*, *egocentric direction*, *pantomime*, *form presentation*, *spatial relation presentation*, *motion quality presentation*, *object-oriented action*, *subject-oriented action*, and *emblem/social convention*. More detailed information about each value definition is provided in Table 1.

Four independent (and naive to the research question) raters were trained and certified to analyse hand movement behaviour according to NEUROGES.[14,21] The videos were analysed without sound to avoid raters of being biased by verbal information. For every video, one rater coded 100% of the data for statistical analysis whereas the second rater coded 25% of the data to establish inter-rater agreement (IA) for all categories of the NEUROGES. IA was established calculating a modified Cohen's kappa according to Holle and Rein.[25] This modified Cohen's kappa takes into account not only the categorization of values but also the temporal overlap of the raters' annotations. Results of the IA are presented as the modified Cohen's kappa and the raw agreement in Table 1. The raw agreement represents the number of agreeing cases divided by the total number of cases. In particular with regard to the fact that the modified Cohen's kappa does not only consider the raters' agreement concerning the value but also the segmentation of behaviour in time (i.e., if there is a unit and when it begins and

Fig. 1. Standardized interview situation and exemplary gestural behaviour of one participant (here: right hand Focus: *in space*; Function: *motion quality presentation*).

Table 1
Short definitions of the Structure, and Function values according to Lausberg[14] and the inter-rater agreement (IA) for each value (according to Holle and Rein[25]).

Focus	Short definition	IA (/raw agreement) for the right hand; left hand; both hands
Within body	1. Acting on body-internal structures, i.e., muscles, tendons, joints, by moving them without touching them; 2. Movements of the shoulders and hips	0.63/0.96; 0.59/0.96; –
On body	Acting on the body surface	0.64/0.82; 0.65/0.82; –
On attached object	Acting on an object that is attached to the body	0.57/0.99; 0.38/0.99; –
On person	Acting on another person's body	0.00/0.99; 0.00/0.99; –
On separate object	Acting on an object that is separate from the body	0.57/0.98; 0.61/0.99; –
In space	Acting in the body-external free space without touching anything	0.69/0.87; 0.65/0.86; –
Function (*only hand movements with a phase structure are considered*)		
Emotion/attitude	Displaying exclusively an emotion or an attitude	0.56/0.95; 0.53/0.95; 0.69/0.91
Emphasis	Setting accents on speech	0.53/0.94; 0.53/0.95; 0.57/0.92
Egocentric deictic	Indicating a location by using an egocentric frame of reference	0.48/0.95; 0.43/0.96; 0.53/0.98
Egocentric direction	Indicating a direction or a route by using an egocentric frame of reference	0.00/0.97; 0.20/0.99; 0.33/0.99
Pantomime	Pretending to perform an action	0.57/0.99; 0.26/0.99; 0.72/0.99
Form presentation	Creating a form	0.46/0.94; 0.00/0.99; 0.80/0.99
Spatial relation presentation	Creating a spatial relation	0.34/0.99; 0.00/0.99; 0.26/0.98
Motion quality presentation	Showing a specific quality of movement	0.72/0.99; 0.44/0.99; 0.70/0.99
Object-oriented action	Changing the external physical world	0.33/0.99; 0.50/0.99; 0.94/0.99
Subject-oriented action	Changing the own physical (and secondarily mental) state	0.80/0.93; 0.72/0.89; 0.81/0.93
Emblem/social convention	Using culture-specific hand signs with conventionalized arbitrary meanings; Function (social convention): conventionalized actions in specific social contexts	0.00/0.99; 0.60/0.99; 1.00/1.00

ends), the agreement in the present investigation was "substantial" in terms of Landis and Koch[26] and with reference to classical kappa scores.[7,12,22]

The data were exported and analysed according to the guidelines for analyses with the NEUROGES–ELAN system.[27] The proportion of time (PoT; seconds/minute) of Focus (measures: *in space*, *on body*, *on attached object*, *on person*, *on separate object*, *within body*), and Function (measures: *emotion/attitude*, *emphasis*, *egocentric deictic*, *egocentric direction*, *pantomime*, *form presentation*, *spatial relation presentation*, *motion quality presentation*, *object-oriented action*, *subject-oriented action*, *emblem/social convention*) units were submitted to (multivariate measures) analyses of variance (mANOVAs) using SPSS (IBM SPSS Statistics version 25). Between-subjects factors comprised groups (*non-concussed*: concussed athletes without a history of a concussion, *asymptomatic* concussed athletes with a PCS score < 10, *symptomatic*: concussed athletes with a PCS score > 10). Multiple post hoc pairwise comparisons were corrected with Bonferroni corrections. An alpha criterion level of <0.05 was employed throughout. Effect size categories were determined as 0.1 = low, 0.3 = medium, and 0.5 = large. Only significant results are reported in Section 3.

3. Results

The mANOVA indicated significant effects of the between-subjects factor group on the proportion of time spent with *in space* hand movements ($F(2, 37) = 3.490$, $p < 0.05$, $\eta^2 = 0.15$). Post-hoc comparisons showed that symptomatic athletes spent significantly more time with *in space* movements (i.e., hand movements that act in the body-external free space without touching anything when compared to non-concussed athletes; $p < 0.05$; Fig. 2).

The mANOVA indicated significant effects of the between-subjects factor group on the proportion of time spent with *motion quality presentation* gestures ($F(2, 37) = 4.571$, $p < 0.05$, $\eta^2 = 0.19$). Post-hoc comparisons of the group effect showed that symptomatic athletes spent significantly more time with *motion quality presen-*

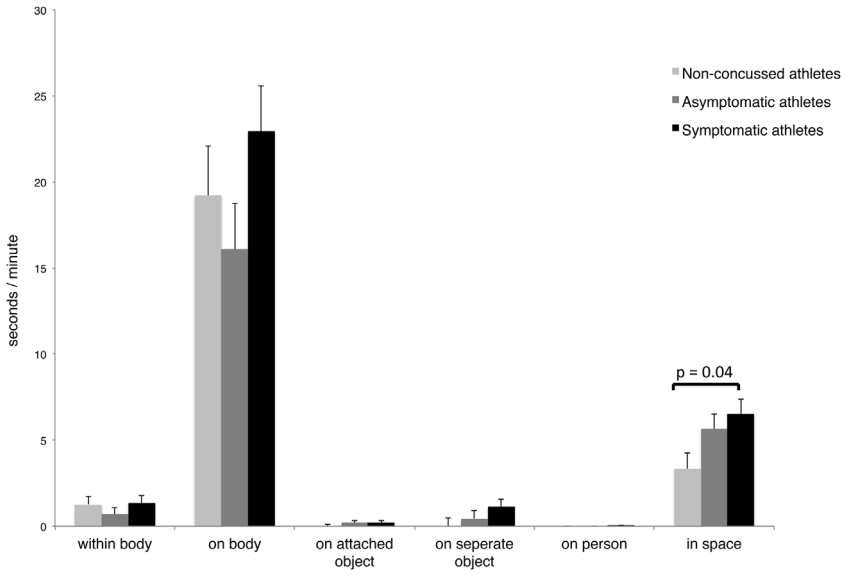

Fig. 2. Mean proportion of time spent with different hand movements (Focus category) between symptomatic, asymptomatic, and non-concussed athletes.

tation gestures, i.e., hand movements that show a specific quality of movement when compared to non-concussed athletes ($p < 0.05$).

4. Discussion

This study reveals that symptomatic athletes with experienced mTBI are characterized by a specific nonverbal gestural profile during concussion assessment protocols. In contrast to non-concussed athletes, symptomatic athletes spent significantly more time with *in space* hand movements and specifically with *motion quality presentation* gestures.

The present data showed that symptomatic athletes spent more time with *in space* hand movements during the concussion assessment protocol when compared to non-concussed athletes. By *in space* hand movements an individual is acting in the body-external free space without touching anything.[14,21] Functionally, these hand movements are gestures. The present findings therefore indicate that concussed athletes increasingly use their hands to externalize mental thoughts. During the protocol, athletes were first asked to describe the concussive event and secondly, report potential symptoms. The fact that symptomatic athletes increasingly "act out" by *in space* hand movements indicates that those athletes externalize more information nonverbally than non-concussed athletes do because they first experienced a SRC, and secondly they still suffer from the aftereffects of the event.

Symptomatic athletes spent particularly more time with *motion quality presentations* when compared to non-concussed athletes. By *motion quality presentations* the hand presents how something/-one moves, i.e., circulating, contracting-expanding, quick, tense, strong, light, or heavy, thus, *motion quality presentation* gestures provide details about the specific quality of movement such as its manner or dynamics.[14,21] Previous research showed that gestures increase particularly during motor imagery descriptions.[28] However, *motion quality presentations* not only concern how something/-one moves, but also provide sensory impressions by indirectly showing how something feels like, e.g., when exploring a soft surface.[14,21] Because the concussion assessment protocol was two-part, i.e. individuals described concussive events and post-concussion symptoms, their hand gestures seem to provide detailed information how concussions look like and how they (still) feel, particularly symptomatic athletes. As a matter of fact, it has been proposed that sensory experiences are specifically transformed into *motion quality presentation* gestures.[14] Because concussive incidents in sports are characterized by velocity and (de/)acceleration of the own body within sportive events,[29] *motion quality presentations* seem to provide nonverbal details about this particular experience and its ongoing aftereffects. Furthermore, the fact that motor-related brain cortices are increasingly activated with previous motor-sensory experiences of an individual[15] indicates that the actual experience of the concussion additionally leads to an increase of gestures that describe motion. The present data therefore evidences that symptomatic athletes spend more time with *in space* movements and specifically, *motion quality presentations* during concussion assessment protocols indicating that those athletes externalize additional information about motion nonverbally when compared to non-concussed athletes.

Thus far, it has not been systematically investigated which information can be derived from the athletes' speech-accompanying gestures during concussion assessment protocols. The fact that symptoms after a concussion are not clearly visible[1] makes it particularly difficult for the medical personnel to decide whether an athlete is ready to return to sport or not. Previous studies pointed out that gestures can provide clinical information about the nature of the a persons' sensation, psychopathology, and/or symptoms that may even not being communicated during speaking.[4–6] Because doctors often disengage from the interaction with their patients focusing on medical records for example,[30] the present findings are of practical relevance for medical personal in order to understand potential post-concussion difficulties and provide appropriate treatment and support. Thus, the present findings can help clinicians to better understand an athletes' post-concussion state.

However, future studies must address several limitations of the present study such as its retrospective study design, its potential recall bias, and the necessity of additional behavioural markers of a concussion. A prospective study design would particularly increase the understanding of whether this gestural behaviour accounts for symptoms after experienced mTBI in general or if it affects only particular athletes who would suffer from long-term impairments after mTBI. The prospective study design would also decrease potential recall bias of the present study. Future studies must also gain more biomarkers (e.g., blood biomarkers, neuroimaging data, etc.) to better understand gestural alterations in relation to the underlying psychopathology of SRC. Still, the present study shows

for the first time that speech-accompanying gestures during concussion assessment protocols can provide additional information about an athlete that experienced mTBI in sports and suffers from ongoing symptomatology.

5. Conclusion

The systematic analysis of hand movements and gestures showed that symptomatic athletes spent more time with *in space* hand movements and *motion quality presentations* during concussion assessment protocols. Increased *in space* movements, which are functionally gestures, and specifically, *motion quality presentations* indicate that the head trauma constitutes a more vivid sensory motor experience that is reflected in more gestural expressions. Thus, the present findings highlight hand movements and speech-accompanying gestures as an important aspect of future post-concussion assessment protocols in order to differentiate athletes who experienced concussive events from athletes who did not.

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