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Neuropsychological functions of nonverbal hand movements and gestures during sports

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ABSTRACT
Emotional body-distant gestures are a prominent feature of winning athletes. Because negative emotions have been associated to increased self-touch behaviour, we investigated the hypothesis that athletes change from a more body-distant nonverbal hand movement behaviour when winning to a body-focused behaviour when losing. Nonverbal hand movements of professional right-handed tennis athletes were video-taped during competition and analyzed by certified raters using the NEUROpsychological GESture(NEUROGES)System. The results showed that losing athletes increase their *irregular, on body,* and *phasic on body* hand movements, particularly with the left hand. *Emotion / attitude rise* gestures with the right hand characterised winning athletes. The data suggest that the nonverbal hand movements of athletes serve different neuropsychological functions. Winners nonverbally express their positive feelings by body-distant gestures but change towards their own body to regulate stress when losing.

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KEYWORDS
Nonverbal behaviour; hemispherical specialisation; self-regulation; emotion expression; gestures

Highlights

- *Irregular, on body,* and *phasic on body* hand movements serve self-regulation when losing during competition
- Athletes express positive emotions by *emotion / attitude rise* gestures
- Nonverbal expression of emotions underlie hemispherically lateralised processes

Introduction

Sport performances are characterised by emotions (Lazarus, 2000), particularly when winning or losing (Aviezer et al., 2012; Koehn & Morris, 2012; Matsumoto & Hwang, 2012; Matsumoto & Willingham, 2006; McCaul et al., 1992; Tracy & Matsumoto, 2008; Whittaker-Bleuler, 1982). Studies that investigated nonverbal expressions during sports reported a particular behaviour during (positive) emotions, i.e. raising arms to express feelings of pride when winning (Matsumoto & Hwang, 2012; Matsumoto & Willingham, 2006; Moesch et al., 2015; Tracy & Matsumoto, 2008). Moesch et al. (2015) communicated that if a team is leading, the higher the athlete's overall number of nonverbal behaviour. The finding that nonverbal post-shot celebrations in elite handball players increased with better performances (Moesch et al., 2015) indicates that winning is associated with a higher overall number of nonverbal behaviour. Whittaker-Bleuler (1982) communicated that raters detected losing tennis athletes more easily by their nonverbal behaviour when compared to winning tennis athletes. This indicates that the nonverbal behaviour of losing athletes might be also prominent when compared to the nonverbal behaviour of winners (Whittaker-Bleuler, 1982). However, the specific nonverbal behaviours of losing athletes and their neuropsychological functions have not been addressed yet. Thus, the aim of this study was to analyze the nonverbal hand movement behaviour of athletes when winning or losing during sport competition, and secondly, whether hand movements and gestures during

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sport competitions serve different neuropsychological functions.

Several neuropsychological studies reported that negative emotional arousal is characterised by particular nonverbal hand movements (Densing et al., 2018; Freedman, 1972; Freedman & Bucci, 1981; Helmich & Lausberg, 2019; Lausberg, 1995; Lausberg & Kryger, 2011; Sousa-Poza et al., 1979; Ulrich & Harms, 1985). In fact, increased *on body*-focused activity, i.e. hand movements that act on the body surface (Lausberg, 2013; Lausberg, 2019) have been reported in psychosomatic disorders and during the description of stressful life experiences (Freedman et al., 1972; Helmich & Lausberg, 2019; Lausberg, 1995; Lausberg & Kryger, 2011; Sousa-Poza et al., 1979; Ulrich & Harms, 1985). Behavioural and Electroencephalography (EEG) results indicate that spontaneous facial self-touch gestures serve the regulation of emotional processes (Grunwald et al., 2014). *Irregular*, rhythmic and *phasic* movements (with medium intensity) showed to serve to self-regulate stress (Densing et al., 2018). Because winning athletes were characterised by hand movements such as "arms away from the body", and "arms raised above the shoulders formed as fists" (Matsumoto & Hwang, 2012; Tracy & Matsumoto, 2008) we hypothesised that athletes would increase their body-distant hand movements when winning but change to body-focused hand movements when experiencing negative emotions in sports, i.e. when losing.

The concept that emotional expression is generally organised in the right hemisphere is still controversially discussed as it opposes the valence-specific hypothesis, which asserts that each half of the brain is specialised for processing emotions, with the left hemisphere being specialised for positive emotions and the right hemisphere being specialised for negative emotions (Adolphs et al., 1996; Ahern & Schwartz, 1979; Borod et al., 1998; Killgore & Yurgelun-Todd, 2007; Silberman & Weingartner, 1986). Recent research using neuroimaging methods during the perception of emotional faces suggests a simultaneous operation of both hemispheres (Killgore & Yurgelun-Todd, 2007). In fact, Killgore and Yurgelun-Todd (2007) postulated that the right hemisphere is specialised in the perception of emotions in general supporting the Right-Hemisphere Hypothesis (RHH). However, different activation patterns in the right and left hemispheres during the perception of negatively and positively valenced stimuli also supported the Valence-Specific Hypothesis (VSH) (Killgore & Yurgelun-Todd, 2007). The spontaneous use of the right and left hands constitutes a valid correlate of hemispheric specialisation (Casasanto & Jasmin, 2010; Hampson & Kimura, 1984; Kimura, 1973; Lausberg et al., 2007; Lausberg & Kita, 2003; Sousa-Poza et al., 1979; Stephens, 1983). If the right hemisphere is dominant for the regulation of mood and affect (Borod et al., 1998; Schwartz et al., 1975), we expect increased spontaneous left-hand movements for either emotion during tennis competitions. If the valence-specific hypothesis of emotional processing applies (Adolphs et al., 1996; Ahern & Schwartz, 1979), we expect that tennis athletes change their spontaneous nonverbal hand movement behaviour from a right-hand laterality during the experience of positive emotions to a left-hand laterality during negative emotions.

Thus, the aim of the present study was to analyze the nonverbal hand movement and gestural behaviour of athletes when winning or losing during sports. Because neuropsychological studies indicate that the nonverbal movement behaviour serves different neuropsychological functions during the experience of positive and negative emotions, i.e. when winning or losing, we hypothesised that athletes would increase their body-distant hand movements and gestures when winning but change a more body-focused behaviour when experiencing negative emotions, i.e. when losing. Furthermore, because the spontaneous use of the right and left hands constitutes a valid correlate of hemispheric specialisation, we additionally explored if the valence-specific hypothesis of emotional processing (Adolphs et al., 1996; Ahern & Schwartz, 1979) applies to the lateralisation of nonverbal hand movements and gestures during sports. We therefore hypothesised that tennis athletes change their spontaneous nonverbal hand movement behaviour from a right-hand laterality during the experience of positive emotions to a left-hand laterality during negative emotions.

Materials and methods

Participants

15 elite, male tennis players (mean age: 27.5 ± 3.5 years; all right-handed; mean Association of Tennis Professionals (ATP)[1] ranking = 232.28 ± 157.85)

[1]Commonly known as the "world rankings" ordering professional players from 1 to 1964 (2019/11/22)

were video-taped during public matches in the 1st league (Bundesliga) in Germany. Handedness was assessed by public information about the player and observation, i.e. which hand was used to play. The athletic directors and the coaches of the clubs provided consent. We did not obtain the athletes individual consent because of the German copyright law concerning professional athletes during public events. The local Ethics Committee of the German Sport University approved the study. The sample has been analyzed and published previously with regards to an athletes spontaneous head movement behaviour during competition (Drewes et al., 2020).

Data

Whole body recordings of professional tennis players (Figure 1) were recorded during competition between rallies for points using a Sony HDR-CX625 Full HD camcorder during five different official match days of the 2018 season of the 1st Bundesliga in July and August at the tennis clubs in Cologne and Aachen, Germany (Koelner THC Stadion Rot-Weiss e.V., TK Kurhaus Aachen). 1.095 videos were recorded in total. All videos were checked and sorted out with respect to the following exclusion criteria: blurred or shaky footage, player had to react to circumstances, which were not related to the match (e.g. tying the shoelaces), the result of the played point was in doubt and needed to be proofed by the chair umpire, the video did not show the whole player or the video duration was too short. From the remaining 926, 20 videos per player were randomly selected (using an online tool for randomisation) and included in the analysis: ten videos of each player's nonverbal response after winning and ten videos after losing. Thus, 300 videos were coded and analyzed. The coding time of athletes' behaviour was defined to four seconds post-point because spontaneous emotional expressions last between 0.5 and 4 s (Ekman & Friesen, 1982; Frank & Ekman, 1993; Matsumoto & Willingham, 2006; Richardson et al., 2000).

Measurements and coding

All occurring hand movements and gestures within the first four seconds post-point were coded using the NEUROGES® (NEUROpsychological GESture) analysis system for nonverbal behaviour (Lausberg, 2013; Lausberg, 2019). Among the existing coding systems for nonverbal behaviour, the NEUROGES analysis system has been chosen as it is objective and reliable (Helmich et al., 2014; Helmich & Lausberg, 2014; Lausberg & Kryger, 2011; Lausberg & Sloetjes, 2009, 2015). Two independent raters were trained and certified to analyze hand movement behaviour according to NEUROGES (Lausberg, 2013; Lausberg, 2019). The videos were analyzed without sound to avoid raters of being biased by auditory information. For each video clip, one rater coded 100% of the data (which was used for statistical analysis) and the second rater coded 25% of the data to establish inter-rater agreement (IA) between raters.

In the present study, we applied the Module I & III of NEUROGES. Module I comprises the categories Activation, Structure, and Focus. Activation (step 1) provides a general impression of an individual's motor activity by the analysis of all occurring hand movements. The Structure category (step 2a) assesses the trajectory, displacement, and the trajectorial structure of hand movements (Lausberg, 2013). In the Structure category (Table 1), hand movements are evaluated concerning if they contain a phase structure or not, thus implying a preparation, complex and retraction phase, which is associated with different levels of cognitive complexity (Lausberg, 2013). Accordingly, five Structure values are distinguished: *phasic, repetitive, shift, aborted,* and *irregular*. *Phasic, repetitive,* and *irregular* movement units are further specified with the Focus category. The Focus category refers to the locus where the hand acts (on) (Lausberg, 2013). It is operationalised by four criteria: presence of physical contact with something/someone (presence vs. absence), quality of physical contact (dynamic vs. static), the object/subject of physical contact, and orientation in absence of dynamic contact (body-external vs. body-internal). Six Focus values are distinguished: *within body, on body, on attached object, on separate object, on person*, and *in space*. Finally, the Structure and Focus values of the units are concatenated (e.g. *phasic in space*). Module III comprises the Function and Type categories. In the Function category, gestures and actions are classified with 11 Function values: *emotion/attitude, emphasis, egocentric deictic, egocentric direction, pantomime, form presentation, spatial relation presentation, motion quality presentation, emblem/social convention, object-oriented action* and *subject-oriented action*. In the Type category, most Function values are further classified with Type values, e.g. a *pantomime*

Figure 1. Exemplary hand movements (left: Losing athletes and *phasic in space* left hand movement; right: Winning athlete and *phasic in space* right hand movement / *emotion / attitude rise* gesture).

Function can be further differentiated into *transitive* or *intransitive* Types (see Table 1 for detailed information). Further information of particular definition of NEUROGES values is provided in Table 1.

Reliability

Interrater agreement (IA) was established calculating a modified Cohen's kappa according to Holle and Rein (2014). This modified Cohen's kappa takes into account not only the categorisation 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. The agreement in the present investigation was "almost perfect" (/"0.81–1.00"; in terms of Landis and Koch (1977)) and with reference to previous scores (Helmich et al., 2014; Helmich & Lausberg, 2014; Lausberg & Kryger, 2011; Lausberg & Sloetjes, 2009, 2015).

Statistics

The data was exported and analyzed according to the guidelines of the NEUROGES-Elan system (Sassenberg & Helmich, 2013). Each NEUROGES category (e.g. Structure with its single values such as for example *phasic*) was statistically analyzed by repeated measures analysis of variance (rmANOVA) and univariate uANOVA using SPSS (IBM SPSS Statistics version 25) with the frequency (F; mean number of value units per minute) of the hand movement values as the dependent variable. Independent factors concerned *outcome* of the played point (won vs. lost) and *hand* (right (rh) vs. left hand (lh) execution). If a value (e.g. *aborted, form presentation,* etc.) Occurred less than five times it was not included in the statistical analysis. If a value was not normally distributed we used non-parametric tests for statistical analyses (Friedman, Wilcoxon). Thus, the following values were included in the statistical analysis: *movement* (Activation); *phasic, repetitive, irregular* (Structure); *in space, on attached object, on separate object, on body* (Focus), *phasic in space*, *phasic on separate object*, *phasic on body*, *phasic on attached object*, *irregular on body* (StructureFocus), *egocentric deictic external target, emotion / attitude (rise, fall, clap), motion quality presentation manner, pantomime transitive active* (FunctionType). Multiple post hoc pairwise comparisons were corrected applying Bonferroni corrections.

Results

Hand movement activation

The rmANOVA revealed a significant effect for *hand* **(**F(1, 14) = 34.380, $p < 0.001$, $\eta^2 = 0.711$) on the frequency of Structure units. Post-hoc comparisons

Table 1. Short definitions and Interrater Agreements (IA) of the hand movement and gesture categories (/values) according to Lausberg (2013, 2019) that were statistically analyzed.

Category	Short definition	IA (/raw agreement) for the left and right hand
Structure		
irregular	movement with no phase structure; trajectory with short paths in various directions; practically no displacement between beginning and end of the unit; potentially continuous in time	0.94/0.99; 1.0/1.0
repetitive	movement with a phase structure: one-dimensional – complex – one-dimensional; during the complex phase the same movement path is used repetitively; discrete in time	1.0/1.0; 1.0/1.0
phasic	movement with a phase structure; the complex phase can be dynamic or static: in a dynamic complex phase there is a one-way movement path, in a static complex phase there is transient motionlessness, in which the part of the body is actively held against gravity; discrete in time	0.95/0.98; 1.0/1.0
Focus		
on body	acting on the body surface	1.0/1.0; 0.93/0.99
on attached object	acting on an object that is attached to the body	1.0/1.0; 1.0/1.0
on separate object	acting on an object that is separate from the body	0.94/0.97; 1.0/1.0
in space	acting in the body-external free space without touching anything	0.96/0.99; 1.0/1.0
Function-Type		
emotion/attitude rise	Dynamic fast raising up of the arms (against gravity); Function: displaying exclusively an emotion or attitude	1.0/1.0; 0.96/0.98
emotion/attitude fall	Letting the arms fall down heavily (giving in to gravity); Function: displaying exclusively an emotion or attitude	1.0/1.0; 1.0/1.0
emotion/attitude clap/beat	Dynamic fast strong movement of the arms; Function: displaying exclusively an emotion or attitude	1.0/1.0; 1.0/1.0
deictic-external target	Indicating a target in the external space by using an egocentric frame of reference; Function: indicating a location by using an egocentric frame of reference	1.0/1.0; 1.0/1.0
pantomime-transitive active	Acting as if with an imaginary (or real) object or counterpart; Function: pretending to perform an action	0.91/0.96; 1.0/1.0
motion quality manner	Presenting a specific type of movement; Function: showing a specific quality of movement	(did not occur for left hand); 1.0/1.0

revealed that hand movements with the right hand significantly increased when compared to hand movements with the left hand ($p < 0.001$). No significant difference was found for hand movement Activation between winning and losing.

Hand movement structure

Non-parametric Friedman tests revealed a significant effect of Structure on the frequency of hand movements ($\chi^2(2) = 27.448$, $p < 0.001$). Post-hoc pairwise comparisons showed that tennis players executed significantly more *phasic* when compared to *irregular* ($p < 0.001$) and *repetitive* hand movements ($p < 0.01$). The Friedman tests for *phasic* hand movements with the *right* and *left* hand when either *winning* or *losing* revealed significance ($\chi^2(3) = 27.786$, $p < 0.001$). Post-hoc pairwise comparisons showed significantly more *phasic* movements with the right hand when winning and when losing when compared to left-hand movements ($p < 0.05$, $p < 0.001$). The Friedman tests for *irregular* hand movements also revealed significance ($\chi^2(3) = 8.705$, $p < 0.05$). Post-hoc pairwise comparisons did not show significant differences. We therefore performed further analyses of pooled data of *irregular* hand movements differentiating between winning and losing. *Irregular* hand movements were significantly increased during losing as when compared to when winning ($\chi^2(1) = 8.000$, $p < 0.01$, Figure 2).

Hand movement Focus

Non-parametric Friedman tests revealed a significant effect of Focus on the frequency of hand movements ($\chi^2(3) = 31.671$, $p < 0.001$). Post-hoc pairwise comparisons showed that tennis players executed significantly more *on separate object* hand movements when compared to *on body* ($p < 0.001$), *on attached object* ($p < 0.001$), and *in space* hand movements ($p < 0.05$).

The Friedman tests for *on separate object* hand movements with the *right* and *left* hand when either *winning* or *losing* revealed significance ($\chi^2(3) = 37.522$, $p < 0.001$). Post-hoc pairwise comparisons showed significantly more *on separate object* movements with the right hand when winning and when losing when compared to movements with the left hand ($p < 0.001$, $p < 0.001$). The Friedman tests for *in space* hand movements with the *right* and *left* hand when either *winning* or

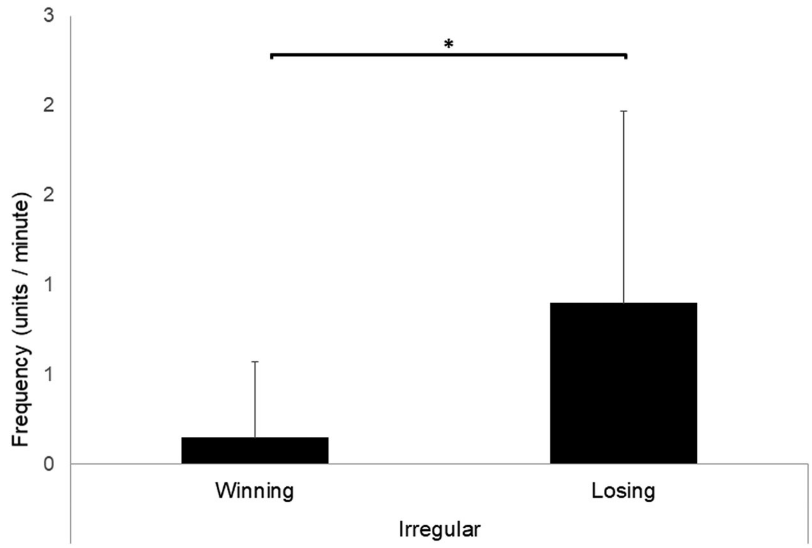

Figure 2. Number of *irregular* movement Structures per minute during winning and losing.

losing revealed significance ($\chi^2(3) = 25.679$, $p < 0.001$). Post-hoc pairwise comparisons showed significantly more *in space* movements with the right hand when winning and when losing when compared to movements with the left hand ($p < 0.01$, $p < 0.05$). The Friedman tests for *on attached object* hand movements with the *right* and *left* hand when either *winning* or *losing* revealed significance ($\chi^2(3) = 23.442$, $p < 0.001$). Post-hoc pairwise comparisons showed significantly more *on attached object* movements with the left hand when winning and when losing when compared to movements with the right hand ($p < 0.05$, $p < 0.05$). The Friedman tests for *on body* hand movements with the *right* and *left* hand when either *winning* or *losing* revealed significance ($\chi^2(3) = 20.734$, $p < 0.001$). Post-hoc pairwise comparisons showed significantly more *on body* movements with the left hand when losing when compared to movements with the right hand ($p < 0.01$, Figure 3).

Hand movement StructureFocus

The Friedman tests for the concatenated Structure-Focus values of the *right* and *left* hand when either *winning* or *losing* revealed significance for *phasic in space* ($\chi^2(3) = 23.328$, $p < 0.001$), *phasic on separate object* ($\chi^2(3) = 37.522$, $p < 0.001$), *phasic on body*

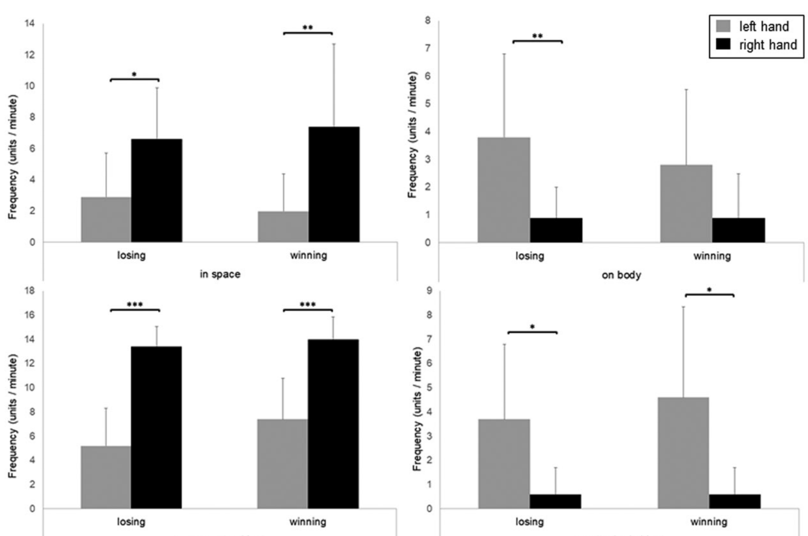

Figure 3. Number of movement Focuses (*in space, on body, on separate object, on attached object*) per minute during winning and losing of the right and left hand.

($\chi^2(3) = 16.152$, $p < 0.01$), *phasic on attached object* ($\chi^2(3) = 23.679$, $p < 0.001$), and *irregular on body* ($\chi^2(3) = 8.705$, $p < 0.05$). Post-hoc pairwise comparisons showed significantly more *phasic in space* movements with the right than left hand when winning ($p < 0.01$) and when losing ($p < 0.05$). Post-hoc pairwise comparisons showed significantly more *phasic on separate object* movements with the right than left hand when winning ($p < 0.01$) and when losing ($p < 0.001$). Post-hoc pairwise comparisons showed significantly more *phasic on attached object* movements with the left than right hand when winning ($p < 0.05$) and when losing ($p <$ 0.05). Post-hoc pairwise comparisons showed significantly more *phasic on body* movements with the left than right hand when losing ($p < 0.05$; Figure 4).

Gestural Function

Wilcoxon tests of gestures when winning or losing revealed a significant effect of *emotion / attitude clap* ($Z = -2.209$, $p < 0.05$), *emotion / attitude rise* ($Z = -2.386$, $p < 0.05$), and *motion quality presentation* ($Z = -2.386$, $p < 0.05$). Post-hoc pairwise comparisons showed that tennis players executed more *emotion / attitude clap* and *motion quality presentation* gestures when losing but *emotion / attitude rise* gestures when winning. The differentiation of *emotion / attitude fall*, *clap*, *rise*, and *shrug* FunctionTypes between the right and left hand when winning and losing resulted in significant effects for *emotion / attitude clap* ($\chi^2(3) = 7.846$, $p < 0.05$) and *emotion / attitude rise* gestures ($\chi^2(3) = 18.774$, $p < 0.001$). Post-hoc pairwise comparisons showed that winning athletes executed significantly more *emotion / attitude rise* with the right than left hand ($p < 0.05$, uncorrected, Figure 5; Table 2).

Discussion

The present study showed that athletes presented a particular nonverbal hand movement and gestural behaviour during competition. Winning athletes were characterised by *emotion / attitude rise* gestures with the right hand. *Emotion / attitude clap* and *motion quality presentation* gestures, *irregular* hand movement Structures, and left hand *on body* Focuses and *phasic on body* StructureFocuses characterised losing athletes. Overall, (right-handed) tennis athletes nonverbally moved their right hand significantly more frequently than their left hand. Athletes executed mostly *phasic* movement Structures with the right hand when winning and when losing. Whereas *on separate object* and *in space* hand movement Focuses were executed with the right hand during winning and losing, *on attached object* and *on body* hand movements were lateralised to the left hand.

Winning athletes executed significantly more *emotion / attitude rise* gestures with the right hand. *Emotion/attitude rise* gestures are characterised by dynamic fast raising up of the arms (against gravity) and *phasic in space* StructureFocuses. The emphasis is on the act of moving up and usually involves the whole arm rather than

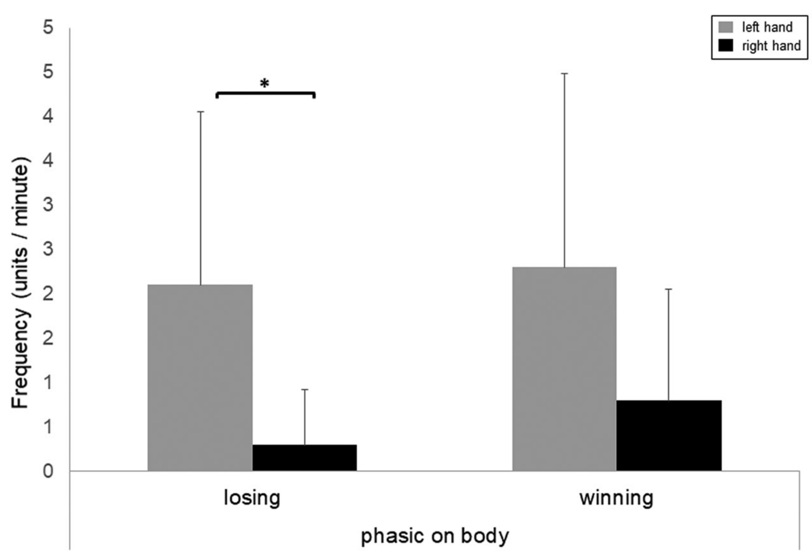

Figure 4. Number of *phasic on body* right and left hand movements per minute during winning and losing.

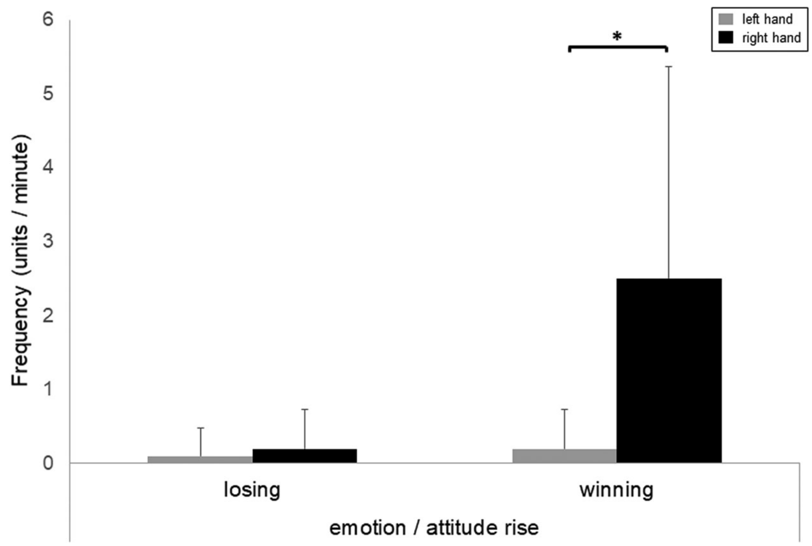

Figure 5. Number of *emotion / attitude rise* gestural FunctionTypes per minute.

only the hand, e.g. a little child throws up the arms with joy (Lausberg, 2013; Lausberg, 2019). Previous research showed that emotions such as triumph, or pride in sports are nonverbally expressed by raising the arms above the shoulders with the hands formed as fists (Matsumoto & Hwang, 2012; Tracy & Matsumoto, 2008). In tennis, the nonverbal gesture commonly known as the "Becker Fist" (Thakur, 2010) constitutes a prominent gesture of success or winning points (Van Raalte et al., 1994).

Table 2. Statistical results.

NEUROGES category	Factor	F / χ2 / Z	df	*p*	Pairwise comparison
Activation.					
Activation.	Hand .	34.380.	1, 14.	< 0.001.	Right hand > left hand.
Structure.					
Structure.	Structure .	27.448.	2.	< 0.001.	Phasic > irregular Phasic > repetitive.
Phasic.	hand / emotion.	27.786.	3.	< 0.001.	Winning: right hand > left hand Losing: right hand > left hand .
Irregular.	hand / emotion.	8.705.	3.	< 0.05.	not significant.
Irregular.	emotion.	8.000.	1.	< 0.01.	Losing > Winning.
Focus.					
Focus.	Focus .	31.671.	3.	< 0.001.	On separate object > on body On separate object > on attached object On separate object > in space.
On separate object.	hand / emotion.	37.522.	3.	< 0.001.	Winning: right hand > left hand Losing: right hand > left hand .
In space.	hand / emotion.	25.679.	3.	< 0.001.	Winning: right hand > left hand Losing: right hand > left hand .
On attached object.	hand / emotion.	23.442.	3.	< 0.001.	Winning: left hand > right hand Losing: left hand > right hand .
On body.	hand / emotion.	20.734.	3.	< 0.001.	Losing: left hand > right hand .
StructureFocus.					
Phasic in space.	hand / emotion.	23.328.	3.	< 0.001.	Winning: right hand > left hand Losing: right hand > left hand .
Phasic on separate object.	hand / emotion.	37.522.	3.	< 0.001.	Winning: left hand > right hand Losing: left hand > right hand .
Phasic on body.	hand / emotion.	16.152.	3.	< 0.01.	Losing: right hand > left hand .
Phasic on attached object.	hand / emotion.	23.679.	3.	< 0.001.	Winning: left hand > right hand Losing: left hand > right hand .
Irregular on body.	hand / emotion.	8.705.	3.	< 0.05.	not significant.
Gestural Function.					
Emotion / attitude clap.	emotion.	−2.209.	1.	< 0.05.	Losing > Winning.
Motion quality presentation.	emotion.	−2.386.	1.	< 0.001.	Losing > Winning.
Emotion / attitude rise.	hand / emotion.	−2.386.	1.	< 0.05.	Winning > Losing .
Emotion / attitude rise.	hand / emotion.	18.774.	3.	< 0.001.	Winning: right hand > right hand.
Emotion / attitude clap.	hand / emotion.	7.846.	3.	< 0.05.	not significant.

The fact that *emotion/attitude rise* gestures were executed more often with the right hand when winning (in right-handed players) indicates that it exists a relationship of positive emotional thinking within the left hemisphere and increased gestures with the contralateral right hand. In fact, right-handed tennis players hold their tennis racket in the right hand but used their dominant right hand to nonverbally express their positive emotions. Thus, athletes spontaneously free their right hand from holding the racket for the nonverbal expression of positive emotions. This points to a strong link between emotional processing and its (lateralised) nonverbal expressions. The valence-specific hypothesis of emotional processing indicates that positive emotions are processed within the left hemisphere (Adolphs et al., 1996; Ahern & Schwartz, 1979; Demaree et al., 2005; Silberman & Weingartner, 1986). The present data therefore shows that *emotion/attitude rise* gestures represent a correlate of positive emotional processes with a lateralisation to the right hand, i.e. the left hemisphere. Thus, the present data supports the valence-specific hypothesis of emotional processing.

Irregular hand movement Structures were significantly increased during losing. In contrast to *phasic* and *repetitive* movements, *irregular* movements do not contain a phase structure. *Irregular* movements usually start where the hand happens to be. These movements do not rely on conceptual thinking but they are non-conceptual sensory-motor activations. It has been therefore proposed that they serve to regulate arousal beyond the mover's awareness (Lausberg, 2013). *Irregular* movements increased in patients with ongoing symptoms after sport-related concussions (Helmich & Lausberg, 2019) and represent a diagnostically relevant behaviour for comorbid depression among patients with social anxiety disorder (Reinecke et al., 2020). *Irregular*, rhythmic and *phasic* movements (with medium intensity) showed to serve to self-regulate stress (Densing et al., 2018). Lausberg (2013) reasoned that *irregular on body* hand movements serve self-regulatory purposes during stressful situations (Lausberg, 2013). In fact, further analyses of the present data showed that athletes executed more *on body* Focuses and *phasic on body* StructureFocuses with the left hand when losing. Behavioural and EEG results indicate that spontaneous facial self-touch gestures serve the regulation of working memory and emotional processes (Grunwald et al., 2014). Furthermore, it exists a left-hand asymmetry for self-touching behaviour (Sousa-Poza et al., 1979), which is already present in children (Trevarthen, 1996). Blonder et al. (1995) reported that right-handers performed “grooming” and “fidgeting” movements preferentially with the left hand (Blonder et al., 1995). Because the present data showed that losing is associated to increased *irregular, on body,* and *phasic on body* hand movements, particularly with the left hand, we therefore conclude that athletes spontaneously executed hand movements to self-regulate negative emotions during competition.

The present results further showed that an athlete's overall nonverbal hand movement frequency did not change between winning and losing points in tennis. Previous studies showed that athletes used their hands to express feelings of pride when winning in sports (Matsumoto & Hwang, 2012; Tracy & Matsumoto, 2008). Moesch et al. (2015) communicated that if a team is leading, the higher the athlete's overall number of nonverbal behaviour. These findings led to the assumption that winners would (nonverbally) move more than losers. In contrast to this assumption, the present study showed that when analyzing all hand movements and gestures after winning or losing points in tennis athletes did not move their hands more or less frequently. In fact, raters previously detected losing athletes more easily by their nonverbal behaviour than winning athletes indicating that losers may be even more expressive by their nonverbal behaviour (Whittaker-Bleuler, 1982). Contrasting results might be grounded in the fact that previous analyses concerned the analysis of nonverbal behaviour by photographs (Matsumoto & Hwang, 2012; Tracy & Matsumoto, 2008). The investigation of photographs does not allow for the analysis of for example *irregular* or *aborted* hand movements. Moesch et al. (2015) used video recordings but did not include *irregular* hand movements in their analysis. Thus, when concerning all hand movement and gestures winners and losers move nonverbally with the same frequency.

The data further showed that (right-handed) tennis athletes nonverbally move their right hand significantly more frequently than their left hand. This is particularly interesting as right-handed tennis athletes hold their racket with the right hand. Further analyses showed that the right hand is particularly used for *phasic* movement Structures (when winning and when losing). The analysis of the Focus and the concatenated StructureFocus values showed that the right hand preference of *phasic* movement Structures is based on more *phasic in space* as well as *phasic on separate object* movements such as manipulations of the racket. *Phasic* hand movements concern hand movements with a phase structure, i.e. hand movements with a preparation, complex, and a retraction phase (Lausberg, 2013; Lausberg, 2019). It has been argued that hand movements with a phase structure reflect cognitive thinking processes and operations with mental concepts (Lausberg, 2013). *Phasic* hand movements can be used to communicate information, e.g. about the action scenes (Helmich et al., 2014) and showed to depend on left hemispheric functions (Helmich & Lausberg, 2014). Mutha et al. (2012) argue that it exists a left hemisphere specialisation for predictive control, i.e. the ability to effectively plan and coordinate motor actions (Mutha et al., 2012). Thus, the present findings support previous conclusions of a left hemispheric specialisation of *phasic* hand movement Structures. Furthermore, whereas *on separate object* and *in space* hand movement Focuses were executed with the right hand during winning and losing, *on attached object* and *on body* hand movements were lateralised to the left hand. As previously described, it exists a left-hand asymmetry for self-touching behaviour (Blonder et al., 1995; Sousa-Poza et al., 1979; Trevarthen, 1996). Thus, the present data further evidences that nonverbal body-focused hand movements are more often executed with the left hand and therefore seem to rely on processes of the right hemisphere.

Limitations of the study

Although the data support the valence-specific hypothesis (Adolphs et al., 1996; Ahern & Schwartz, 1979; Demaree et al., 2005; Silberman & Weingartner, 1986), the present analysis solely concerned right-handed tennis players. Thus, and because of the fact that right- and left-handed individuals have demonstrated opposite patterns of asymmetry during affect perception (Reuter-Lorenz et al., 1983), the present data cannot be generalised for left-handed athletes. Future studies must therefore concern the behaviour of left-handed athletes in order to understand the effects of handedness on emotional processes in the two hemispheres. Another limitation concerns the sample as we included only 15 male professional athletes. It has been reported that male subjects show more lateralisation of brain function than females (Bowers & LaBarba, 1988; Hines et al., 1992; Russo, 2000). Men and women may also differ in their lateralisation of emotional processing (Cahill et al., 2001; Killgore & Yurgelun-Todd, 2001). In fact, a recent meta-analysis of neuroimaging findings concluded that lateralisation effects of emotional processes differ between men and women and are region specific (Wager et al., 2003). Furthermore, the nonverbal behaviour of a tennis athlete might be also influenced by interaction with the opponent or other persons such as spectators and/or coaches. Thus, future studies must include more participants and address the issue of different lateralised processes of emotions in men and women.

Conclusion

The present study showed that athletes do not move nonverbally more or less when winning or losing during sport competitions but for different neuropsychological reasons. In fact, winning athletes nonverbally express their positive emotions by *emotion/attitude rise* gestures with the right hand, i.e. the left hemisphere. On the contrary, hand movements of losing athletes seem to serve self-regulation (*irregular, on body,* and *phasic on body* hand movements) and are lateralised to the left hand, i.e. the right hemisphere. Thus, the data not only points out that the hands serve different neuropsychological functions during competition but also confirm the valence-specific hypothesis of emotional processing during a real life situation.

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Data availability

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