Neuropsychologia 114 (2018) 118–124

Contents lists available at ScienceDirect

Neuropsychologia

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

EEG alpha activity during imagining creative moves in soccer decision-making situations☆

Andreas Fink[a,1,*], Christian Rominger[a], Mathias Benedek[a], Corinna M. Perchtold[a], Ilona Papousek[a], Elisabeth M. Weiss[a], Anna Seidel[b], Daniel Memmert[b]

[a] Institute of Psychology, University of Graz, Austria
[b] Institute of Exercise Training and Sport Informatics, German Sport University Cologne, Germany

ARTICLE INFO

Keywords:
Creativity
Alpha power
Soccer
Motor imagery
Visual attention

ABSTRACT

This study investigated task-related changes of EEG alpha power while participants were imagining creative moves in soccer decision-making situations. After presenting brief video clips of a soccer scene, participants had to imagine themselves as the acting player and to think either of a creative/original or an obvious/conventional move (control condition) that might lead to a goal. Performance of the soccer task generally elicited comparatively strong alpha power decreases at parietal and occipital sites, indicating high visuospatial processing demands. This power decrease was less pronounced in the creative vs. control condition, reflecting a more internally oriented state of information processing characterized by more imaginative mental simulation rather than stimulus-driven bottom-up processing. In addition, more creative task performance in the soccer task was associated with stronger alpha desynchronization at left cortical sites, most prominently over motor related areas. This finding suggests that individuals who generated more creative moves were more intensively engaged in processes related to movement imagery. Unlike the domain-specific creativity measure, individual's trait creative potential, as assessed by a psychometric creativity test, was globally positively associated with alpha power at all cortical sites. In investigating creative processes implicated in complex creative behavior involving more ecologically valid demands, this study showed that thinking creatively in soccer decision-making situations recruits specific brain networks supporting processes related to visuospatial attention and movement imagery, while the relative increase in alpha power in more creative conditions and in individuals with higher creative potential might reflect a pattern relevant across different creativity domains.

1. Introduction

The domain of sports could be considered as “worthwhile field to study behavior in a complex context“ (Memmert, 2011, p. 373), as it facilitates the investigation of creative performance in an ecologically valid way (cf. Lieberman, 2000; Runco and Sakamoto, 1999; Simonton, 2003). To date, a considerable amount of research demonstrated that successful solutions in sport game situations within different kinds of sports require processes that are very similar to those seen in various creativity-related domains (for an overview see Memmert, 2015). For instance, in order to achieve original and successful solutions in soccer game situations, players need to base their decisions on all relevant information from their environments (positions or anticipated behavior of teammates and opponents, players emerging unexpectedly, etc.), and in order to select the most promising solution they continuously need to consider both the actual stimulus constellation and task-relevant information stored in memory (e.g., inhibiting inappropriate solution approaches, evaluating the efficacy and appropriateness of the imagined or anticipated move, etc.). Creative solutions in sport situations thus seem to be characterized by similar processes as other forms of creative problem solving such as divergent and convergent modes of thinking (Guilford, 1967), and they seem to strongly rely on attentional processes (e.g., attentional breadth; Furley et al., 2010; Memmert, 2007; Memmert and Furley, 2007), domain-specific knowledge and associative abilities – processes that are known as important ingredients of creativity.

EEG and functional imaging studies on creativity have greatly contributed to the common notion that creativity is a multifaceted construct strongly linked to cognitive functions such as attention and cognitive control. In reviewing functional imaging studies in the field of

☆ This research was supported by a grant from the Austrian Science Fund (FWF): I 2901-B27, and the German Research Foundation (DFG): ME 2678/23-1.
* Correspondence to: University of Graz, Institute of Psychology, Universitaetsplatz 2/III; A-8010 Graz, Austria.
E-mail address: andreas.fink@uni-graz.at (A. Fink).
[1] Web: http://psychologie.uni-graz.at/de/biologische-psychologie/.

https://doi.org/10.1016/j.neuropsychologia.2018.04.025
Received 21 January 2018; Received in revised form 17 April 2018; Accepted 23 April 2018
Available online 24 April 2018

creativity, Gonen-Yaacovi et al. (2013) identified a “core creativity network” including regions of the lateral prefrontal cortex, which have consistently been found as being implicated in various higher order executive processes such as fluency, flexibility or cognitive control. Moreover, it included a set of brain regions (i.e., left angular, superior temporal, and the inferior frontal gyri) which have been associated with semantic processes such as the activation and retrieval of internal memory representations (Binder et al., 2009). A similar picture of findings emerged in the EEG domain, where studies revealed consistent findings linking creative processes to increased alpha power levels in the brain (e.g., Benedek et al., 2011; Benedek et al., 2014; Fink and Benedek, 2014; Fink et al., 2017; Hao et al., 2016; Lopata et al., 2017). While decreases in alpha power during the performance of a particular task (relative to a baseline) are thought to reflect an increased excitability level of neurons in the involved cortical areas (Neuper and Pfurtscheller, 2001), and hence a functional correlate of brain activation (Klimesch et al., 2007), increases in alpha power have been interpreted to reflect the attenuation of stimulus-driven bottom-up stimulation that may interfere with successful task performance. Thus, the frequently reported alpha power increases during creative ideation indicate a state of high internal, top-down processing demands (e.g., Klimesch, 2012; von Stein and Sarnthein, 2000), which may facilitate internally-oriented processes including imagination and effective search and retrieval of memory representations during the generation of novel ideas (Fink and Benedek, 2014).

Since most of the available neuroscience studies on creativity focused on (verbal) divergent thinking demands, it could be regarded as an important step forward to investigate functional patterns of brain activity also during other types of creative behavior which involve more ecologically valid demands. In this study we investigated EEG alpha activity during the generation of creative solutions in soccer decision-making situations (with scenes from real soccer games), motivated by recent behavioral research emphasizing the particular relevance of creative processes in this domain (e.g., Memmert, 2015). Each soccer scene was presented via brief video clips. Participants were required to imagine themselves as the acting player and – depending on the respective task instruction – to think either of a creative/original (possible and promising) or an obvious/conventional move (control condition) that might lead to a goal. The general experimental test design is relatively highly standardized and has been validated extensively in different sport settings (basketball: Furley et al., 2010; Memmert and Furley, 2007; soccer: Memmert et al., 2013). A particular advantage of the employed task is that the participants are forced to react to many different comparable situations, facilitating the reliable analysis of EEG brain activity patterns. It was expected that imagining creative solutions in soccer decision-making situations is reflected in task-related power changes in the EEG alpha band, which has been shown as being particularly sensitive to different creativity-related demands (Fink and Benedek, 2014). Evidence in the visual creativity domain (e.g., Aziz-Zadeh et al., 2013; Boccia et al., 2015; Rominger et al., 2018) further leads us to expect that brain networks supporting visuospatial processes and motor related imagery may likewise play a crucial role in generating creative solutions in soccer game situations.

2. Methods

2.1. Participants

Forty five men participated in this study. Due to technical problems during EEG assessment two participants had to be excluded from further analyses, resulting in a sample of $n = 43$ in the age range between 19 and 31 years ($M = 24.19$; $SD = 3.16$). As important inclusion criteria, participants were required to have been actively playing soccer for at least ten years (at least once per week). On average, participants have been actively playing soccer for approx. 18 years ($M = 17.71$, $SD = 3.35$), and they indicated to play soccer for about 4 h per week ($M = 4.20$, $SD = 2.98$). All participants were hobby to amateur soccer players, the majority of them (67%) was actively playing in various soccer clubs (the highest soccer league the participants indicated they had ever played ranged up to the third-highest national league), 26% of the participants were active as soccer trainers. All participants were right-handed (assessed by the hand dominance test, HDT; Steingrüber and Lienert, 1971; Papousek and Schulter, 1999), non-medicated, and written informed consent was obtained. The study was approved by the local ethics committee.

2.2. Assessment of creative potential

Trait creative potential was assessed by a figural creativity test (“Test zum Schöpferischen Denken – Zeichnerisch”, TSD-Z; Urban and Jellen, 1995) requiring participants to complete abstract picture fragments (printed on a test sheet) in a free-associative, original way. The time limit was 15 min. According to the instructions given in the test manual, the generated drawings were evaluated with respect to 14 different criteria (e.g., unconventionality, inclusion of new elements, graphic combinations, etc.), resulting in a total score for the creative potential of the participants.

2.3. Experimental task during EEG assessment

Participants worked on a modified version of the standardized video task in soccer (SVT-S), in which participants were required to mentally generate moves with the intention to score a goal in a given soccer decision-making situation. The objectivity, reliability and validity of the SVT-S has been established in previous studies (Memmert, 2013; Memmert et al., 2013). As shown in Fig. 1, each trial started with the presentation of a fixation cross for a time period of 10 s. Afterwards brief video clips of soccer decision-making situations with scenes from real soccer games were shown (ranging from 2 to 12 s in length). The fixed image of the soccer scene marked the beginning of the idea generation period, in which participants had to imagine themselves as the acting player of the attacking team (who was marked by an underline in the fixed image) and – depending on the respective task instruction – to think either of an obvious/conventional (control condition) or a creative/original move to score a goal. The respective task condition was indicated by a lightened (i.e., creative/original) or switched off (i.e., obvious/conventional) bulb, respectively (see Fig. 1). During the idea generation period, the fixed image of the soccer scene remained visible on the screen and the players of the attacking team were assigned with numbers to make them clearly identifiable. Participants were not allowed to speak during the idea generation period. They were instructed to press the IDEA button with the dominant right hand as soon as they thought of a solution/move (otherwise the idea generation period stopped automatically after 15 s), and then (during the response period, 10 s) to vocalize the imagined move briefly (e.g., pass to 1, then pass to 3, and then header shot by 5, etc.). Participants were instructed to vocalize only one solution per response interval. The oral responses were recorded via a microphone and transcribed for further analyses. In each condition (creative/original and control condition) 15 items were presented, resulting in a total number of 30 trials. The presentation of trials was randomized and the EEG recording session took about 15–20 min.

2.4. Quantification of task performance

The 30 videos of the SVT-S were taken from previous studies of our laboratory (see e.g., Memmert et al., 2013). In that studies, the videos were shown to a group of participants who had to find as many solutions, which lead to a goal, as possible. Afterwards the given answers, along with the respective video, were shown up to four soccer experts with the highest soccer qualification (UEFA A license) to rate the first pass of the different solutions of each video with regard to originality

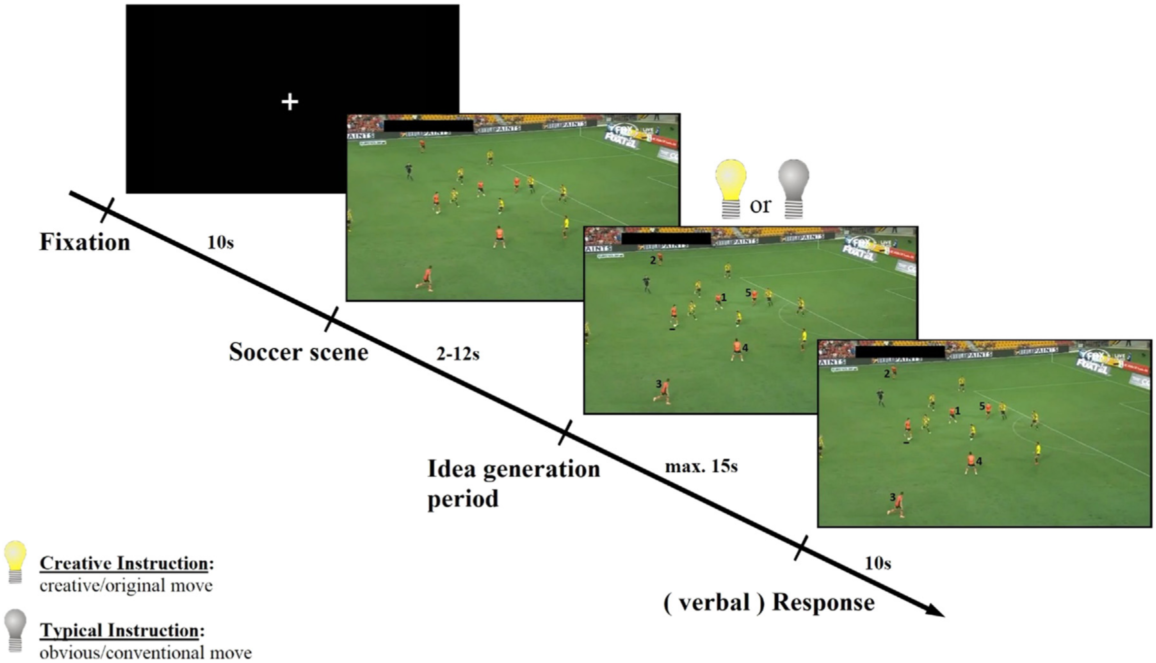

Fig. 1. Schematic time course of a trial of the SVT-S during EEG assessment. A trial started with the presentation of a fixation cross for 10 s. Afterwards brief video clips of soccer decision-making situations were shown (ranging from 2 to 12 s). During the idea generation period a fixed image of the soccer scene remained visible on the screen, signaling participants to imagine themselves as the acting player, and – depending on the respective task instruction – to think either of an obvious/conventional (switched off bulb, control condition) or a creative/original move (lightened bulb) to score a goal. When they thought of a solution/move they were instructed to press the IDEA button, and to vocalize the imagined move (max 10 s; e.g., pass to 1, then pass to 3, etc.).

on scales from 1 to 5 (1 is not original and 5 is very original; Memmert et al., 2013) or 1–7 (1 is not original at all and 7 is very original). The inter-judge reliability coefficient was above the critical limit of .80 (intraclass correlation coefficient). As Thomas et al. (2015) stated this is a valid inter-judge reliability. As a result, answer categories were formed by the first pass of the answer. The experts were pointed to remember the target orientation (to make a goal), when rating the answers. Basically, the entire set of video clips allowed a broad range of less to more original task solutions. According to the originality range of the solutions, videos tending to show more variability at the lower end of the originality spectrum were assigned to the control condition (15 videos), while the remaining 15 videos which tended to show more variability at the upper end of the originality spectrum were assigned to the creative condition.

To quantify the performance of the SVT-S in this study, the originality of each individual response during EEG assessment in both the control and the creative condition was assessed. This was realized in the following steps: The answers of the participants for each video were assigned to a particular category formed by the first pass of the given answer. Most of these responses were consistent with the rated categories established in previous studies (e.g., Memmert et al., 2013). In 11 of the 30 videos the participants gave answers that did not fit into one of the categories. These answers were then rated by another soccer expert with the highest soccer qualification (UEFA A license) with regard to their originality on a scale from 1 to 5, or 1–7. This expert was not informed about the task the participants had, but only was shown the videos with the respective answers. The average of all ratings for one answer category was the originality score a participant received for his/her answer in this category. So a participant obtained an originality score for each answer he/she has given to each video. This score was then divided by the maximum for this video item (5 or 7) to make the scores comparable with each other. Thus, the highest originality score is 1 and the lowest is 0. Afterwards all scores were averaged for each participant, to obtain a general originality score.

2.5. EEG recording and analysis

The EEG was recorded by 19 active electrodes, positioned according to the 10–20 system (actiCAP; Brain Products™) with a common EEG amplifier (Brainvision actiCHamp Research Amplifier, Brain Products™; 1000 Hz sampling rate) in a separate and quiet room. The ground electrode was located on the forehead, the reference electrode on the nose. Vertical and horizontal electrooculograms (EOGs) were measured with two bipolar channels for horizontal and vertical eye movements. Electrode impedances were kept below 30 kΩ for all electrodes. The EEG signals were recorded with a high cutoff filter of 280 Hz. EEG data were preprocessed by removing drifts and low pass filtering (50 Hz). The resulting signal was manually checked for artifacts. As in other studies concerning divergent thinking (e.g., Fink et al., 2017), task-related power changes (TRP) between the reference and the activation period were quantified for upper alpha power (10 – 12 Hz) for an electrode *i* by subtracting the Medians of the log-transformed power of the reference period ($Pow_{i,\ reference}$) from the activation period ($Pow_{i,\ activation}$), according to the formula: $TRP_i = Median(log(Pow_{i,\ activation}))$-$Median(log(Pow_{i,\ reference}))$. Negative values indicate a decrease of task-related alpha power from the reference to the activation period (alpha desynchronization), while positive values express a power increase (Pfurtscheller and Lopes da Silva, 1999).

For TRP analysis, an 8 s interval from the 10 s reference period served as reference interval (from 1 s after onset of the fixation cross until 1 s before the offset; see Fig. 1) and two 1 s time intervals reflecting different stages of the creative thinking process were used as activation intervals: a) the interval from 250 ms to 1250 ms after stimulus onset, which captures early stimulus processing; and b) the interval 1250–250 ms prior to the idea button press, which reflects processes related to finalizing task solution.

TRP scores in the upper alpha band (10–12 Hz) were computed for each electrode position and participant. The band power values (μV^2) were obtained by squaring the filtered EEG signals. Only activation periods with at least 250 ms and reference periods with at least 2000 ms artifact free EEG-recording were used for statistical analyses.

2.6. Statistical analyses

The analytical/statistical approach used in this study pursued two important objectives. First, to investigate the overall pattern of task-related alpha power changes during the performance of the soccer decision-making situations, a GLM for repeated measures involving the factors TASK instruction (creative/original solution vs. obvious/conventional), STAGE (stimulus onset vs. finalizing task solution), HEMISPHERE (left vs. right) and AREA (eight electrode positions in each hemisphere) was performed on the TRP in the upper alpha band. In applying a within-subjects approach, this analysis sought to test potential differences in task-related alpha power changes as a function of the instruction (creative vs. obvious) and the stage of the thinking process (stimulus onset vs. finalizing task solution).

In a second set of analyses, we pursued an individual differences approach to test whether alpha power changes during the creative task condition of the SVT-S were modulated on the one hand by individual differences in the domain-specific creativity measure obtained during the performance of the soccer task, and on the other hand by individual differences in global creative potential, as assessed by the psychometric creativity test. For this reason, a GLM for repeated measures was computed in considering AREA and HEMISPHERE as within-subjects factors and task performance during the SVT-S (i.e., originality) as continuous between-subjects factor. An analogous GLM was performed for the creative potential score of the TSD-Z. These analyses were restricted to the second stage of the creative thinking process (i.e., finalizing task solution), since preliminary analyses suggested that task performance effects on TRP were more pronounced while participants finalized the moves as compared to early stimulus processing.

To illustrate significant effects of the continuously distributed between-subjects factors (task performance in the SVT-S and creative potential in the TSD-Z, respectively), predicted TRP values were calculated for one standard deviation below and one standard deviation above the sample mean using standard regression analysis. In case of violations of sphericity assumptions, degrees of freedom were Greenhouse-Geisser corrected. Post-hoc comparisons were performed using Tukey's Honestly Significant Differences (HSD) test. Estimates of effect sizes are given in terms of partial eta-squared measures (η_p^2). All statistical tests were performed with $\alpha = .05$ (two-tailed).

3. Results

3.1. Task-related alpha power changes during performance of the soccer Task

Performance of the soccer decision-making situations was generally associated with comparatively strong decreases of upper alpha power at parietal and occipital sites, as reflected in a significant main effect AREA (F(2.03, 85.34) = 61.06, $p < .001$, $\eta_p^2 = .59$). A significant interaction between AREA and HEMISPHERE (F(4.70, 197.29) = 4.70, $p = .001$, $\eta_p^2 = .10$) indicated that alpha power decreases were particularly apparent at right parietal sites (P8 vs. P7, $p = .02$, as assessed by Tukey HSD test).

In addition, the GLM yielded a significant main effect of STAGE (F(1, 42) = 17.37, $p < .001$, $\eta_p^2 = .29$), along with a significant interaction between STAGE and AREA (F(3.24, 136.23) = 4.80, $p = .003$, $\eta_p^2 = .10$). Accordingly, there was a general increase in alpha desynchronization from stimulus onset to finalizing the move, which was most pronounced at central cortical sites (Tukey tests revealed significant STAGE related differences at all cortical sites, apart from a trend at F7/8, $p = .06$).

There was also a significant interaction involving the factor TASK instruction (TASK x AREA: F(5.19, 218.06) = 2.51, $p = .03$, $\eta_p^2 = .06$). As shown in Fig. 2, the creative condition was associated with relatively more alpha power (i.e., less alpha power decreases) at parietal and occipital sites than the control condition in which obvious/conventional task solutions were required. Tukey HSD tests, however, failed to reveal any significant TASK related differences.

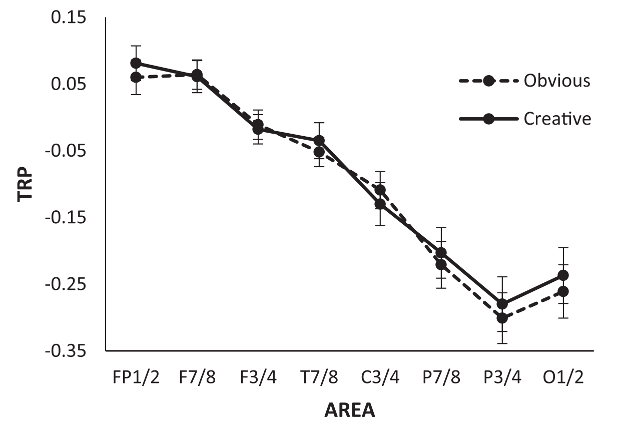

Fig. 2. Task-related changes in alpha power (TRP) during imagining obvious/conventional (control condition) vs. creative/original moves in soccer decision-making situations. Negative TRP values indicate decreases in alpha power from the reference to the activation period.

3.2. Task-related alpha power changes during the performance of the creative condition of the soccer task as a function of task performance and creative potential

The GLM involving the task performance score yielded significant main effects of AREA (F(2.58, 105.92) = 2.93, $p = .04$, $\eta_p^2 = .07$) and HEMISPHERE (F(1,41) = 5.24, $p = .03$, $\eta_p^2 = .11$), along with a significant interaction between HEMISPHERE and TASK PERFORMANCE (F(1,41) = 5.45, $p = .02$, $\eta_p^2 = .12$).

The pattern of this interaction indicates that individuals who generated more original moves showed stronger alpha power desynchronization at left- than right-hemispheric sites, while individuals showing less original performance in the SVT-S displayed slightly stronger alpha power decreases over the right than the left hemisphere. Though the interaction between HEMISPHERE, TASK PERFORMANCE and AREA failed to reach statistical significance (F(7,287) = 1.65, $p = .12$, $\eta_p^2 = .04$), Fig. 3 seems to suggest that the hemisphere by task performance interaction is driven primarily by central (C3 vs. C4) and frontal sites (F3 vs. F4; see Fig. 3). In fact, additional tests for each homologous cortical sites (GLM with HEMISPHERE and TASK PERFORMANCE as factors for each homologous electrode pairs) revealed significant hemisphere by task performance interactions only at F3 vs. F4 (F(1,41) = 5.41, $p = .03$, $\eta_p^2 = .12$), and at C3 vs. C4. (F(1,41) = 5.06, $p = .03$, $\eta_p^2 = .11$).

The GLM for the creative potential of the individuals (TSD-Z) revealed a significant main effect of the TSD-Z score (F(1,41) = 10.69, $p = .002$, $\eta_p^2 = .21$), suggesting that higher creative potential is associated with less pronounced alpha power decreases or even with small increases in alpha power (Fig. 4). There were no other significant effects involving the creative potential score.

3.3. Behavioral results

The creative/original condition of the SVT-S resulted in more original responses than the control condition (creative: $M = .69$, $SD = .05$; control: $M = .61$, $SD = .04$; $t(42) = 11.18$, $p < .001$). The mean reaction time in the creative condition ($M = 7504$ ms, $SD = 1935$) was significantly longer than in the control condition ($M = 6087$ ms, $SD = 1450$; $t(42) = 8.41$, $p < .001$).

There was a significant correlation between creative task

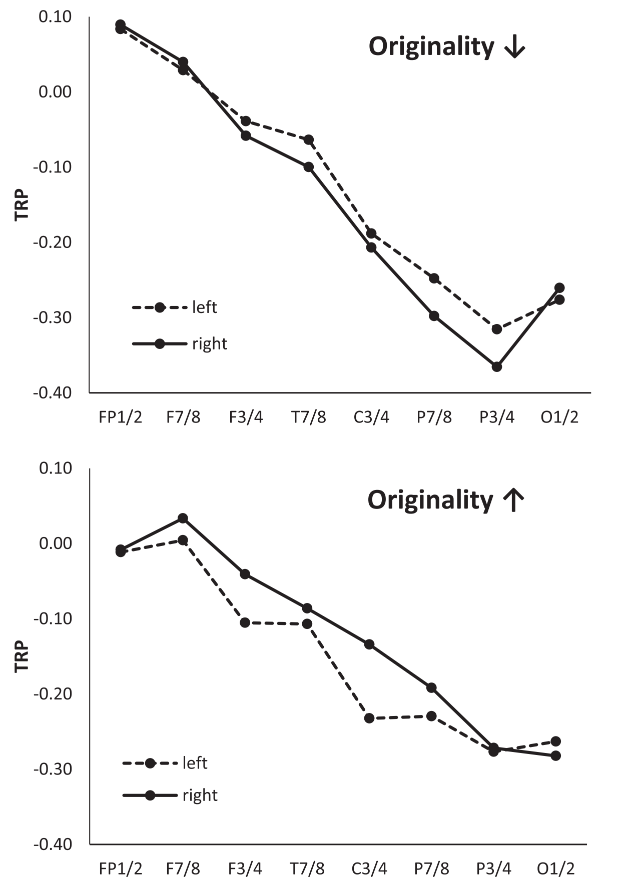

Fig. 3. Task-related changes in alpha power (TRP) during imagining creative/original moves in soccer decision-making situations as a function of task performance. Negative TRP values indicate decreases in alpha power from the reference to the activation period. Predicted TRPs (calculated using standard regression analysis) are plotted separately for each cortical position for task performance changes one SD below (lower performance) and one SD above (higher performance) the mean.

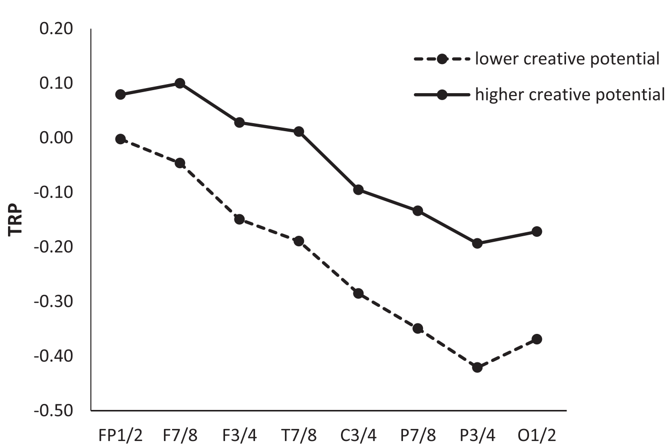

Fig. 4. Task-related changes in alpha power (TRP) during imagining creative/original moves in soccer decision-making situations as a function of creative potential (TSD-Z). Negative TRP values indicate decreases in alpha power from the reference to the activation period. Predicted TRPs (calculated using standard regression analysis) are plotted separately for each cortical position for changes one SD below (lower creative potential) and one SD above (higher creative potential) the mean.

performance in the control and in the creative condition ($r = .38$, $p = .01$), while none of the task performance scores was significantly associated with trait creative potential (TSD-Z; control condition: $r = -.16$, $p = .31$; creative condition: $r = .01$, $p = .97$).

4. Discussion

Thinking of possible ways of how moves in soccer decision-making situations can lead to a goal, elicited comparatively strong alpha power decreases at parietal and occipital sites. Similar to EEG studies on figural creative ideation (Rominger et al., 2018), this finding indicates high visuospatial processing demands during the performance of complex soccer scenarios, involving processes such as mental rotation, spatial transformation, imaginary manipulation of objects (e.g., Pfurtscheller et al., 1994; Riecanský and Katina, 2010; Williams and Rippon, 1995), or the imagination of movements (Pfurtscheller et al., 2006). In addition, significant effects related to the stage of the thinking process (early stimulus processing vs. finalizing task solution) suggested that alpha power changes do not occur uniformly across the thinking process, but rather vary as a function of time (for similar evidence see Jaarsveld et al., 2015; Rominger et al., 2018; Schwab et al., 2014). As the findings of this study suggest, the pattern of alpha power changes prior to finalizing the move was clearly different from the one during stimulus onset. In specific, alpha desynchronization was generally stronger prior to finalizing the move, probably indicating increasing cognitive load, but especially over central cortical sites. In light of the large overlap of neural networks implicated in motor imagery and overt movements (e.g., Chong and Stinear, 2017), and the crucial role of motor areas in movement imagery (e.g., Miller et al., 2010; Pfurtscheller and Neuper, 1997; Villiger et al., 2013), this finding hints at increasing demands on movement related imagery at this stage of the thinking process.

The overall result pattern that finding solutions in soccer decision-making situations elicited strong alpha power desynchronization at parietal and occipital sites is clearly different from the EEG alpha studies on verbal creative ideation, where often task-related increases during creative ideation (relative to baseline) were found (see e.g., Fink and Benedek, 2014). But critically, task instruction (creative vs. obvious moves) also had a significant impact on the results. When participants were required to generate creative/original moves, alpha desynchronization at parietal and occipital sites was slightly less pronounced than during the control condition in which conventional/obvious task solutions were required (Fig. 2). This corresponds to slightly higher alpha power levels during the creative relative to the control condition. This relative increase of alpha power in creative vs. less creative conditions at posterior cortical sites is well in line with current literature on EEG correlates underlying creative ideation (e.g., Benedek et al., 2014; Fink and Benedek, 2014; Fink et al., 2009; Schwab et al., 2014), and may indicate a more internally oriented state of information processing during creative ideation that is less strongly concerned with specific stimulus-based bottom-up processing demands.

Another important finding of this study that nicely fits into current creativity literature was that higher trait creative potential was associated with less pronounced alpha power decreases or even with small increases in alpha power during the performance of the creative condition of the soccer task (Fig. 4). This global positive association of creative potential with alpha power may indicate that individuals with higher creative potential were engaged in more internally driven imaginative thought processes while generating creative moves in the soccer decision-making task (cf. Fink and Benedek, 2014). Strikingly, the findings concerning the domain-specific creativity measure in the soccer task were diametrically in the opposite way. As the finding of this study suggest, more original task performance in the soccer task was associated with stronger alpha power desynchronization at left than right cortical sites. Supplemental post hoc analyses moreover revealed that this effect was most prominent at left motor related sites (C3 and F3; see Fig. 3). It hence seems that individuals who generated more creative task solutions were more intensively engaged in processes related to motor or movement imagery. In a similar vein, a study of

Villiger et al. (2013) found comparatively strong activation in left motor related brain regions while participants were simultaneously observing and imagining performing a motor action (foot movement) in contrast to only observing the action. Left motor related brain regions have also been found to be implicated in the visuospatial creativity domain (Aziz-Zadeh et al., 2013; Boccia et al., 2015), indicating that processes such as motor imagery and motor planning are important components of visual creativity (see also Rominger et al., 2018).

The finding that the domain-specific creativity score of the SVT-S and the global trait creative potential score of the TSD-Z modulated task-related alpha power changes during the performance of the soccer task in a different way, nicely demonstrates that creativity and its neural underpinnings are specific to a particular domain (Baer, 1998). Similar to the idea that an individual who is generally physically very active and athletic might not necessarily be a good soccer player, this finding also strongly supports the notion that creativity is a function of relevant knowledge/expertise in a specific domain (Simonton, 2000; Weisberg, 1999).

Regarding the effect at left motor related sites in this study, a potential point of criticism could be that the effect simply reflects motor related processes in anticipating pressing the response button with the dominant right hand. Such an alternative explanation seems unlikely, since there appears to be no obvious reason to assume more preparatory or anticipatory motor related processes prior to the button press in more vs. less creative task performers. Additionally and perhaps even more importantly, re-running the same analysis that was performed for the creative condition of the SVT-S also for the control condition, revealed no single statistically significant effect. Another limitation of this study is that the analysis of task-related power changes in the EEG was restricted to the alpha frequency band. Given that in this study the soccer decision-making task was investigated in the creativity context for the very first time, focusing on the alpha band guarantees best possible comparability with existing creativity literature, which has accumulated a considerable amount of evidence linking alpha activity to different creativity-related task demands (e.g., Fink and Benedek, 2014). Additionally and equally important, there are well-accepted theoretical accounts on the functional meaning of EEG oscillations in the alpha band (Klimesch et al., 2007; Klimesch, 2012). However, this does not necessarily mean that creativity-related effects are restricted solely to this frequency band. There is also an increasing amount of evidence that oscillatory brain activity in other frequency bands is relevant in creative cognition as well (such as the delta or beta band: see e.g., Bhattacharya and Petsche, 2005; Boot et al., 2017). A very recent study even showed increases in ideational fluency and originality (as assessed by a divergent thinking task) as a result of rapid beta neurofeedback training (Agnoli et al., 2018). Future research is thus particularly challenged to complement existing evidence on alpha and creativity also by other EEG parameters and frequency bands. Also, in this study participants were explicitly instructed to think either of an obvious or a creative move. It would be also interesting to see the "typical" behavior of participants in such soccer decision-making situations and how this is reflected in brain activity. In this particular context, a larger number of trials (soccer scenes) would be needed for reliable comparisons of brain activity patterns in response to spontaneous variation in the creativity of responses within a person. Such an approach would provide an important additional test of the role of alpha oscillations in creative soccer task performance, and complement the individual differences approach adopted here. Finally, future studies in the soccer domain should also consider the positions of the players (e.g., forward, midfield, backfield, goalkeeper, etc.). This would also facilitate to assess the exciting research question whether creativity-related brain activity patterns during soccer task performance vary as a function of the player position.

5. Conclusion

This study took an entirely novel approach to investigate creativity-related brain activity patterns in more complex creative behavior that involves more ecologically valid task demands. Taken together, the findings add to relevant literature in several important ways. First, the findings of this study strongly support the idea that creativity is not a uniform process, but rather involves manifold cognitive processes that depend on the specific creativity domain. In line with the common notion that creativity relies on various neural networks, and different creativity domains are associated with different brain regions (e.g., Boccia et al., 2015), this study showed that thinking creatively in sport decision-making situations recruits specific brain networks supporting processes related to visuospatial attention and movement imagery, while the relative increase in alpha power in more creative conditions and in individuals with higher creative potential might reflect a pattern relevant across different creativity domains. These latter findings also suggest that the association between creative cognition and alpha activation (e.g., Fink and Benedek, 2014) broadly generalizes to the realistic context of playing soccer. Second, the findings of this study suggest that playing soccer is a highly complex process including cognitive processes such as visuospatial attention, motor and movement imagery, along with top-down processing demands – processes that are also known as crucial components of creativity.

Acknowledgement

The authors wish to thank Sabrina Grünwald and Lisa Pursch for their valuable help in data collection.

References

Agnoli, S., Zanon, M., Mastria, S., Avenanti, A., Corazza, G.E., 2018. Enhancing creative cognition with a rapid right-parietal neurofeedback procedure. Neuropsychologia. http://dx.doi.org/10.1016/j.neuropsychologia.2018.02.015. (published online ahead of print).

Aziz-Zadeh, L., Liew, S.-L., Dandekar, F., 2013. Exploring the neural correlates of visual creativity. Soc. Cogn. Affect. Neurosci. 8, 475–480. http://dx.doi.org/10.1093/scan/nss021.

Baer, J., 1998. The case for domain specificity of creativity. Creat. Res. J. 11, 173–177. http://dx.doi.org/10.1207/s15326934crj1102_7.

Benedek, M., Bergner, S., Könen, T., Fink, A., Neubauer, A.C., 2011. EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. Neuropsychologia 49, 3505–3511. http://dx.doi.org/10.1016/j.neuropsychologia.2011.09.004.

Benedek, M., Schickel, R.J., Jauk, E.V., Fink, A., Neubauer, A.C., 2014. Alpha power increases in right parietal cortex reflects focused internal attention. Neuropsychologia 56, 393–400. http://dx.doi.org/10.1016/j.neuropsychologia.2014.02.010.

Bhattacharya, J., Petsche, H., 2005. Drawing on mind's canvas: differences in cortical integration patterns between artists and non-artists. Hum. Brain Mapp. 26, 1–14. http://dx.doi.org/10.1002/hbm.20104.

Binder, J.R., Desai, R.H., Graves, W.W., Conant, L.L., 2009. Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. Cereb. Cortex 19, 2767–2796. http://dx.doi.org/10.1093/cercor/bhp055.

Boccia, M., Piccardi, L., Palermo, L., Nori, R., Palmiero, M., 2015. Where do bright ideas occur in our brain? Meta-analytic evidence from neuroimaging studies of domain-specific creativity. Front. Psychol. 6, 1195. http://dx.doi.org/10.3389/fpsyg.2015.01195.

Boot, N., Baas, M., Mühlfeld, E., de Dreu, C.K.W., van Gaal, S., 2017. Widespread neural oscillations in the delta band dissociate rule convergence from rule divergence during creative idea generation. Neuropsychologia 104, 8–17. http://dx.doi.org/10.1016/j.neuropsychologia.2017.07.033.

Chong, B.W.X., Stinear, C.M., 2017. Modulation of motor cortex inhibition during motor imagery. J. Neurophysiol. 117, 1776–1784. http://dx.doi.org/10.1152/jn.00549.2016.

Fink, A., Benedek, M., 2014. EEG alpha power and creative ideation. Neurosci. Biobehav. Rev. 44, 111–123. http://dx.doi.org/10.1016/j.neubiorev.2012.12.002.

Fink, A., Graif, B., Neubauer, A.C., 2009. Brain correlates underlying creative thinking: eeg alpha activity in professional vs. novice dancers. NeuroImage 46, 854–862. http://dx.doi.org/10.1016/j.neuroimage.2009.02.036.

Fink, A., Weiss, E.M., Schwarzl, U., Weber, H., Loureiro de Assunção, V., Rominger, C., Schulter, G., Lackner, H.K., Papousek, I., 2017. Creative ways to well-being: reappraisal inventiveness in the context of anger evoking situations. Cogn. Affect. Behav. Neurosci. 17, 94–105. http://dx.doi.org/10.3758/s13415-016-0465-9.

Furley, P., Memmert, D., Heller, C., 2010. The dark side of visual awareness in sport –

inattentional blindness in a real-world basketball task. Atten. Percept. Psychophys. 72, 1327–1337. http://dx.doi.org/10.3758/APP.72.5.1327.

Gonen-Yaacovi, G., de Souza, L.C., Levy, R., Urbanski, M., Josse, G., Volle, E., 2013. Rostral and caudal prefrontal contribution to creativity: a meta-analysis of functional imaging data. Front. Hum. Neurosci. 7, 465. http://dx.doi.org/10.3389/fnhum.2013.00465.

Guilford, J.P., 1967. The Nature of Human Intelligence. McGraw Hill, New York.

Hao, N., Ku, Y., Liu, M., Hu, Y., Bodner, M., Grabner, R.H., Fink, A., 2016. Reflection enhances creativity: beneficial effects of idea evaluation on idea generation. Brain Cogn. 103, 30–37. http://dx.doi.org/10.1016/j.bandc.2016.01.005.

Jaarsveld, S., Fink, A., Rinner, M., Schwab, D., Benedek, M., Lachmann, T., 2015. Intelligence in creative processes: an EEG study. Intelligence 49, 171–178. http://dx.doi.org/10.1016/j.intell.2015.01.012.

Klimesch, W., 2012. Alpha-band oscillations, attention, and controlled access to stored information. Trends Cogn. Sci. 16, 606–617. http://dx.doi.org/10.1016/j.tics.2012.10.007.

Klimesch, W., Sauseng, P., Hanslmayr, S., 2007. EEG alpha oscillations: the inhibition-timing hypothesis. Brain Res. Rev. 53, 63–88. http://dx.doi.org/10.1016/j.brainresrev.2006.06.003.

Lieberman, M.D., 2000. Intuition: a social cognitive neuroscience approach. Psychol. Bull. 126, 109–137. http://dx.doi.org/10.1037//0033-2909.126.1.109.

Lopata, J.A., Nowicki, E.A., Joanisse, M.F., 2017. Creativity as a distinct trainable mental state: an EEG study of musical improvisation. Neuropsychologia 99, 246–258. http://dx.doi.org/10.1016/j.neuropsychologia.2017.03.020.

Memmert, D., 2015. Teaching Tactical Creativity in Sport: Research and Practice. Routledge, Abingdon.

Memmert, D., 2013. Tactical creativity. In: McGarry, T., O'Donoghue, P., Sampaio, J. (Eds.), Routledge Handbook of Sports Performance Analysis. Routledge, Abingdon, pp. 297–308.

Memmert, D., 2011. Sports and creativity. In: Runco, M.A., Pritzker, S.R. (Eds.), Encyclopedia of Creativity. Academic Press, San Diego, pp. 373–378.

Memmert, D., Furley, P., 2007. "I spy with my little eye!": breadth of attention, inattentional blindness, and tactical decision making in team sports. J. Sport Exerc. Psychol. 29, 365–381. http://dx.doi.org/10.1123/jsep.29.3.365.

Memmert, D., 2007. Can creativity be improved by an attention-broadening training program? An exploratory study focusing on team sports. Creat. Res. J. 19, 1–12. http://dx.doi.org/10.1080/10400410701397420.

Memmert, D., Hüttermann, S., Orliczek, J., 2013b. Decide like Lionel Messi! The impact of regulatory focus on divergent thinking in sports. J. Appl. Social. Psychol. 43, 2163–2167. http://dx.doi.org/10.1111/jasp.12159.

Miller, K.J., Schalk, G., Fetz, E.E., den Nijs, M., Ojemann, J.G., Rao, R.P.N., 2010. Cortical activity during motor execution, motor imagery, and imagery-based online feedback. PNAS 107, 4430–4435. http://dx.doi.org/10.1073/pnas.0913697107.

Neuper, C., Pfurtscheller, G., 2001. Event-related dynamics of cortical rhythms: frequency-specific features and functional correlates. Int. J. Psychophysiol. 43, 41–58. http://dx.doi.org/10.1016/S0167-8760(01)00178-7.

Papousek, I., Schulter, G., 1999. Quantitative assessment of five behavioural laterality measures: distributions of scores and intercorrelations among right-handers. Laterality 4, 345–362. http://dx.doi.org/10.1080/713754344.

Pfurtscheller, G., Lopes da Silva, F.H., 1999. Event-related EEG/MEG synchronization and desynchronization: basic principles. Clin. Neurophysiol. 110, 1842–1857. http://dx.doi.org/10.1016/S1388-2457(99)00141-8.

Pfurtscheller, G., Neuper, C., 1997. Motor imagery activates primary sensorimotor area in humans. Neurosci. Lett. 239, 65–68. http://dx.doi.org/10.1016/S0304-3940(97)00889-6.

Pfurtscheller, G., Brunner, C., Schlögl, A., Lopes da Silva, F.H., 2006. Mu rhythm (de)synchronization and EEG single-trial classification of different motor imagery tasks. NeuroImage 31, 153–159. http://dx.doi.org/10.1016/j.neuroimage.2005.12.003.

Pfurtscheller, G., Neuper, C., Mohl, W., 1994. Event-related desynchronization (ERD) during visual processing. International. J. Psychophysiol. 16, 147–153. http://dx.doi.org/10.1016/0167-8760(89)90041-X.

Riecanský, I., Katina, S., 2010. Induced EEG alpha oscillations are related to mental rotation ability: the evidence for neural efficiency and serial processing. Neurosci. Lett. 482, 133–136. http://dx.doi.org/10.1016/j.neulet.2010.07.017.

Rominger, C., Papousek, I., Perchtold, C.M., Weber, B., Weiss, E.M., Fink, A., 2018. The creative brain in the figural domain: distinct patterns of EEG alpha power during idea generation and idea elaboration. Neuropsychologia. http://dx.doi.org/10.1016/j.neuropsychologia.2018.02.013. (published online ahead of print).

Runco, M.A., Sakamoto, S.O., 1999. Experimental studies of creativity. In: Sternberg, R.J. (Ed.), Handbook of Creativity. Cambridge University Press, Cambridge, pp. 62–92.

Schwab, D., Benedek, M., Papousek, I., Weiss, E.M., Fink, A., 2014. The time-course of EEG alpha power changes in creative ideation. Front. Hum. Neurosci. 8, 310. http://dx.doi.org/10.3389/fnhum.2014.00310.

Simonton, D.K., 2000. Creativity: cognitive, personal, developmental, and social aspects. Am. Psychol. 55, 151–158. http://dx.doi.org/10.1037/0003-066X.55.1.151.

Simonton, D.K., 2003. Scientific creativity as constrained stochastic behavior: the integration of product, person and process. Psychol. Bull. 129, 475–494. http://dx.doi.org/10.1037/0033-2909.129.4.475.

Steingrüber, H.-J., Lienert, G., 1971. Hand-Dominanz-Test: H-D-T; Handanweisung. Hogrefe, Göttingen.

Thomas, J.R., Nelson, J.K., Silverman, S.J., 2015. Research Methods in Physical Activity, 7th ed. Human Kinetics, Champaign, IL.

Urban, K.K., Jellen, H.G., 1995. TSD-Z: Test zum Schöpferischen Denken - Zeichnerisch (Manual). TCT-DPTest for Creative Thinking-Drawing Production (Manual). Swets Test Services, Frankfurt.

Villiger, M., Estévez, N., Hepp-Reymond, M.-C., Kiper, D., Kollias, S.S., Eng, K., Hotz-Boendermaker, S., 2013. Enhanced activation of motor execution networks using action observation combined with imagination of lower limb movements. PLoS ONE 8, e72403. http://dx.doi.org/10.1371/journal.pone.0072403.

von Stein, A., Sarnthein, J., 2000. Different frequencies for different scales of cortical integration: from local gamma to long range alpha/theta synchronization. Int. J. Psychophysiol. 38, 301–313. http://dx.doi.org/10.1016/S0167-8760(00)00172-0.

Weisberg, R.W., 1999. Creativity and knowledge: a challenge to theories. In: Sternberg, R.J. (Ed.), Handbook of Creativity. Cambridge University Press, New York, pp. 226–250.

Williams, J.D., Rippon, G., 1995. Psychophysiological correlates of dynamic imagery. Br. J. Psychol. 86, 283–300. http://dx.doi.org/10.1111/j.2044-8295.1995.tb02562.x.