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Brain correlates underlying creative thinking: EEG alpha activity in professional vs. novice dancers

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ABSTRACT

Neuroscientific research on creativity has revealed valuable insights into possible brain correlates underlying this complex mental ability domain. However, most of the studies investigated brain activity during the performance of comparatively simple (verbal) type of tasks and the majority of studies focused on samples of the normal population. In this study we investigate EEG activity in professional dancers ($n=15$) who have attained a high level of expertise in this domain. This group was compared with a group of novices ($n=17$) who have only basic experience in dancing and completed no comprehensive training in this field. The EEG was recorded during performance of two different dancing imagery tasks which differed with respect to creative demands. In the first task participants were instructed to mentally perform a dance which should be as unique and original as possible (improvisation dance). In the waltz task they were asked to imagine dancing the waltz, a standard dance which involves a sequence of monotonous steps (lower creative demands). In addition, brain activity was also measured during performance of the Alternative Uses test. We observed evidence that during the generation of alternative uses professional dancers show stronger alpha synchronization in posterior parietal brain regions than novice dancers. During improvisation dance, professional dancers exhibited more right-hemispheric alpha synchronization than the group of novices did, while during imagining dancing the waltz no significant group differences emerged. The findings complement and extend existing findings on the relationship between EEG alpha activity and creative thinking.

Creativity is important in many areas of our everyday life and it "… is seen as a good attribute for people to possess" (Simonton, 2000, p. 151). Creativity is needed in science, pedagogy or education, just as in the industrial or economic domain. However, despite of its crucial role in almost all areas of our everyday life, no conclusive definition of this mental ability construct has been achieved yet. There is some agreement that creativity can be defined as the ability to produce work that is novel, useful and generative (e.g. Sternberg and Lubart, 1996). According to that view, creativity is regarded as a performance trait which is preferably manifested in original, valuable and socially accepted ideas, products, or works of art. This view is also reflected in the assumption that creativity can be assessed by means of performance measures derived from creative thinking tasks or psychometric tests which typically require participants to generate, for instance, unusual uses of conventional, everyday objects (i.e. the so-called Alternative Uses test), to find original slogans (such as in the imagination subscales of the Berlin intelligence structure test, BIS; Jäger et al., 1997) or to find original solutions to a given problem situation (see e.g. Torrance Tests of Creative Thinking, TTCT; Torrance, 1966). Such psychometric creativity tests usually provide measures for ideational fluency (i.e. number of ideas), originality (uniqueness/statistical infrequency) of ideas, as well as measures for flexibility of thinking (i.e. the ability to produce different types of ideas or ideas out of different categories, respectively; cf. Guilford, 1950).

The availability of psychometric measures of creativity as well as the availability of modern neuroimaging techniques such as EEG or fMRI enables us to look at the brain when engaged in the performance of different creative thinking tasks. Meanwhile, more and more studies have addressed this exciting research question and have yielded valuable insights into possible neural correlates involved in creative thinking (for reviews see e.g. Dietrich, 2004; Fink et al., 2007). For instance, brain activity has been investigated in response to divergent (as opposed to convergent) thinking (Mölle et al., 1999), during insightful problem solving or the subjective experience of "AHA!" (Jung-Beeman et al. 2004), likewise during the performance of classic creativity tasks such as the unusual uses test (Folley and Park, 2005), match problem solving tasks (Goel and Vartanian, 2005), or in relation to musical creativity or visual art (Bhattacharya and Petsche, 2005).

From a methodological perspective, there are several approaches to investigate brain correlates underlying creative thinking. One way is to contrast brain activity patterns during the performance of more "free-associative" (i.e. more creativity-related) tasks with activity

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patterns during the performance of more conventional problem solving tasks. Mölle et al. (1999), for instance, reported higher EEG complexity during the performance of more "free-associative" type of tasks which could be the result of a larger number of independently oscillating neural assemblies during this type of thinking. Similar evidence was reported by Jaušovec and Jaušovec (2000) who observed an association between EEG coherence measures in the alpha band and the level of creativity needed to solve the given problem. Specifically, performing an essay writing task was related to an increase in intra- and inter-hemispheric cooperation between far distant brain regions (frontopolar and parietooccipital regions) which could be indicative of a stronger involvement of the long cortico-cortical fiber system during creative thinking. In another EEG study Razumnikova (2000) observed strong increases in short- and long-distance EEG coherence patterns (particularly in the EEG beta frequency band) during performance of a divergent thinking task which also suggests that this type of thinking involves increased functional cooperation or connectivity of different brain regions. In line with this, we also observed evidence that performance of more "free-associative" tasks of creative thinking (such as responding creatively to hypothetical or utopian situations) exhibited a stronger task-related synchronization of EEG alpha activity than the performance of more "convergent" or intelligence-related tasks (such as originally completing given word ends; cf. Fink et al., 2006, 2007).

The finding that convergent vs. divergent modes of thinking are associated with different patterns of brain activation has been also underpinned by Carlsson et al. (2000) in measuring rCBF. The authors observed a stronger level of anterior prefrontal brain activation during performance of the alternative uses task (which is known as a fairly good measure of creativity), as compared with the more intelligence-related verbal fluency task. Also, in using fMRI, Goel and Vartanian (2005) recently report evidence that solving match problems (known as classic divergent thinking problems) which require the on-going generation and evaluation of multiple hypotheses resulted in significant activation in regions of the left dorsal lateral prefrontal cortex (BA 46) and the right ventral lateral prefrontal cortex (BA 47) relative to a rather convergent control task (evaluation of the accuracy of given solutions).

Another promising approach in the neuroscientific study of creative thinking is to investigate brain activity patterns that are associated with the generation of highly creative (as opposed to less creative) ideas. This exciting research question has been stimulated by Jung-Beeman et al. (2004) who investigated brain correlates (by means of fMRI and EEG) underlying subjective experience of insight or "AHA!". The authors had their participants work on remote associate problems (finding a compound to three given stimulus words) and compared brain activity during solutions that were accompanied by subjective experience of insight with those that were solved without insight. The fMRI study revealed increased neural activity in the right-hemispheric anterior superior temporal gyrus for insight relative to non-insight trials. The EEG study yielded evidence that insight solutions were associated with a sudden burst of EEG activity in the gamma band in the same brain area (beginning 0.3 s prior to insight) and with a burst of alpha power observed over right posterior parietal cortex (approximately 1.4–0.4 s before response).

Stimulated by Jung-Beeman et al.'s approach Fink and Neubauer (2006; see also Grabner et al., 2007) have also investigated as to how brain states during the production of highly original ideas might be differentiated from those observed during the production of less original ideas. During creative idea generation participants were required to press a so-called "IDEA-button" whenever they had an idea and to vocalize it subsequently. Thus we were able to measure EEG brain activity in relation to the production of each single idea. Analyses revealed that more original (as opposed to less original) ideas were accompanied by a stronger task-related synchronization of alpha activity in centroparietal (and to some minor extent also in anteriofrontal) regions of the cortex. This finding is not only in agreement with Jung-Beeman et al.'s (2004) "alpha effect" observed during subjective experience of "AHA!" (i.e. an increase in alpha activity in insight as compared to non-insight solutions), but also fits into previous research reports which also found parietal brain regions being critically involved in divergent or creative thinking tasks (e.g. Bechtereva et al., 2004).

The neuroscientific study of creative thinking has been also addressed from an individual differences perspective. In this context, individuals high vs. low in creativity are compared with respect to different activity patterns of the brain (e.g. Bhattacharya and Petsche, 2005; Carlsson et al., 2000; Chávez-Eakle et al., 2007; Jaušovec, 2000; Martindale et al., 1984). For instance, the early work by Martindale and Hines (1975) reveals evidence that highly creative individuals exhibited higher alpha wave activity (which was interpreted as lower cortical arousal) while performing the Alternate Uses Test. Similarly, in Martindale and Hasenfus (1978) highly creative individuals showed higher levels of alpha than low creative subjects during an inspirational phase (i.e. while they had to make up a creative story) but not during an elaboration phase. In a more recent study Jaušovec (2000) also observed evidence that highly creative individuals showed higher EEG alpha power measures than did average creative individuals while they were engaged in the performance of creativity problems.

In a study in our laboratory (Fink et al., 2009) we investigated EEG alpha activity during the generation of alternative, original uses of common, everyday objects (e.g. "umbrella", "cap", "pencil", "vase of flowers" etc.). Based on the originality of ideas participants produced during this task the total sample was divided into a group of lower and into a group of higher originality. We observed evidence that the generation of alternative uses was generally associated with a diffuse, topographically widespread pattern of task-related alpha synchronization. In addition, higher original individuals exhibited a comparatively strong hemispheric asymmetry with respect to alpha activity (with a stronger task-related alpha synchronization in the right than in the left hemisphere) while in lower original individuals no hemispheric differences emerged.

Though empirical studies in this field of research are comparatively rare, existing empirical evidence may uncover valuable information about potential brain correlates underlying creative thinking. Particularly EEG activity in the alpha frequency band has proven to be fairly sensitive to creativity-related demands (Bazanova and Aftanas, 2008; Fink et al., 2006, 2007, 2009; Jaušovec, 2000; Jung-Beeman et al., 2004; Razumnikova, 2007; Martindale, 1999; Sandkühler and Bhattacharya, 2008). Specifically, on the basis of existing evidence in this field it can be concluded that EEG alpha activity varies as a function of the creative demands of a task (the more creative a task the higher the level of alpha activity; cf. Fink et al., 2007), as a function of originality (higher originality is accompanied by more alpha; Fink and Neubauer, 2006; Grabner et al., 2007) or subjective experience of insight (more alpha in insight vs. non-insight solutions; Jung-Beeman et al., 2004) and as a function of an individuals' creativity level (more alpha in higher creative individuals; Fink et al., 2009; Jaušovec, 2000; Martindale and Hines, 1975). However, in this particular context some important issues are still unresolved. First and foremost, the majority of creative thinking tasks which are used in this field of research are comparatively simple or basic types of tasks and most of the experimental studies utilized tasks consisting of verbal stimulus material. Such tasks can be indicative only of basic aspects of creative thinking and future neuroscientific research in this field is challenged by the investigation of more complex, "real-life" creativity tasks. And second, most of the studies in this field of research investigated brain activity patterns in samples of university students or in samples of the normal population. Neuroscientific studies in more specific creativity-related samples (i.e. artists, composers, musicians etc.) are rare. Noteworthy exceptions are the studies by Bhattacharya and Petsche

(2005) and Chávez-Eakle et al. (2007) who investigated brain activity in samples of scientists or artists (see also Petsche, 1996).

In the present study we investigate EEG alpha activity in professional dancers who have attained a high level of expertise in ballet or modern dance (i.e. several years of professional experience in this domain). The group of professional dancers ($n=15$) is compared with a group of novices ($n=17$) who has only basic experience in dancing and completed no comprehensive training in this domain. The EEG was recorded during the performance of two different dancing imagery tasks which considerably differed with respect to their creative demands. In the dance improvisation task they were instructed to mentally perform a dance which should be as unique, original or creative as possible. Participants were instructed to let their minds free wander and to think of possible dances no one else would think of. Unlike this, in the task with lower creative demands participants were asked to imagine dancing the waltz, a common standard dance which involves a sequence of monotonous steps or movements. Participants were required to do only the basic steps of the waltz, they were not allowed to perform any other variations. In addition, brain activity was also measured during performance of the Alternative Uses test. On the basis of existing evidence on the relationship between EEG alpha activity and creativity we expect that performing the free-associative dance improvisation task is accompanied by more alpha activity than performing the less creative waltz task. Also, professional dancers are hypothesized to exhibit more alpha during imagining dancing (especially during the dance improvisation task) than the group of novices. Finally, professional dancers are also supposed to show a stronger alpha response during the performance of the well-known Alternative Uses task.

Methods

Participants

Thirty-four participants took part in this study. Due to extensive EEG artifacts the data of two persons had to be excluded from further analyses. The remaining sample ($n=32$) consisted of 15 professional dances (11 females; mean age = 26.93, $SD=6.41$) and 17 novices (14 females; mean age = 23.94, $SD=3.67$). The group of professional dancers has completed a comprehensive training in dance and has perennial professional experience in this domain; they all started dancing already in early childhood. Most of them were dancers in ballet companies or students who participate in the training of the Royal Academy of Dance (http://www.rad.org.uk/). The dancers have engagements in Austria and in several countries across Europe and exercise dancing five up to seven times per week. As a criterion for participation in this study professional dancers needed to have experience in improvisation dance. Participants of the novices group, in contrast, completed only a basic course in dancing and received no regular training in dance. The completion of a basic course in dance (in which common standard dances like the waltz are taught) was a condition of participation for the novices in order to ensure that they are familiar enough with this dance to imagine it appropriately. All participants were healthy (no history of prior neurological or psychiatric diseases; determined by self-report), right-handed and gave written informed consent prior to the EEG recording session.

Psychometric tests

Prior to the EEG sessions participants were tested with respect to personality (by means of the NEO-PI-R by Costa and McCrae; translated into German by Ostendorf and Angleitner, 2004). The NEO-PI-R allows for the assessment of the "Big Five" of personality, i.e. neuroticism, extraversion, openness to new experiences, agreeableness and conscientiousness. Along with scores for these broad personality dimensions the NEO-PI-R also provides measures for specific personality aspects (such as impulsivity, activity, sociability, competence, ambitiousness etc.). Prior to the EEG recording session we measured anxiety by means of a German version of Spielberger's state-trait anxiety inventory (STAI; Laux et al., 1981).

Experimental tasks

Participants worked on three different experimental tasks while the EEG was recorded: 1.) The dance improvisation task, 2.) the waltz task and 3.) the Alternative Uses (AU) task.

In the dance improvisation task participants were asked to mentally perform a free-associative improvisation dance. They were instructed to put themselves in a large bright hall and to think of original dancing movements. They were instructed to let their minds wander and to be as original, unique or creative in imagining the dance. Preferably they should mentally create movements no one else would think of. In this task participants were *not* allowed to follow a specific choreography or to imagine movements of a conventional standard dance (or to reproduce from memory, respectively). The task performance interval was 3 min. Subsequent to the EEG recording session participants were interviewed with respect to dance performance by asking them specific questions about the imagined dance (e.g. dance positions, description of movements, dynamical aspects, style etc.).

In the waltz task participants were instructed to imagine dancing the waltz which is a well-known standard dance in Austria. Unlike the free-associative dance improvisation task, the waltz task involves rather low creative demands. Participants are again requested to put themselves in a large, bright hall and to imagine dancing the waltz (alone and not with a partner). The waltz involves a sequence of monotonous movements, requiring participants to dance according to predetermined dancing steps. The task performance interval was again 3 min. Subsequent to the EEG session participants were interviewed with respect to their experiences in performing the waltz dance.

In the AU task, participants had to think of unusual/original uses of conventional everyday objects such as a *tin* (example answers: "mirror", "exhaust for a car") or a *brick* (example answers: "candleholder", "karate training"). Four test items were given (*tin*, *brick*, *sock*, *ballpen*) with a time limit (or a response interval, respectively) of 3 min each.

Apparatus/EEG recording

The EEG was measured (BrainAmp amplifier) by means of gold electrodes (9 mm diameter) located in an electrode cap in 33 positions (according to the international 10–20 system with inter-spaced positions); a ground electrode was located on the forehead, the reference electrode was placed on the nose. To register eye movements, an electrooculogram (EOG) was recorded bipolarly between two gold electrodes diagonally placed above and below the inner respectively the outer canthus of the right eye. The EEG signals were filtered between 0.1 Hz and 100 Hz; an additional 50 Hz notch filter was applied to avoid power line contamination. Electrode impedances were kept below 5 kΩ for the EEG and below 10 kΩ for the EOG. All signals were sampled at a frequency of 500 Hz.

All tasks started with the presentation of a fixation cross for a time period of 15 s, which served for the assessment of pre-stimulus reference power. Subsequently, the test instructions were presented on a computer screen, and participants started to work on the experimental tasks, for a time period of 3 min each. For the presentation of the AU task an external response-console consisting of an "IDEA"- and an "ENTER"-button was used. Participants were instructed to press the IDEA-button whenever they had an idea related to the item presented on screen. Then, by pressing the IDEA-button, a message appeared on screen asking the participants to vocalize the idea (which was recorded by the experimenter) and to confirm it finally with the ENTER-button upon which the stimulus reappears on the screen. That way EEG artifacts caused by typing or free-hand writing can be avoided.

Brain activity during the performance of experimental tasks was quantified by means of task-related power (TRP) changes in the EEG (Pfurtscheller, 1999). Task-related power at an electrode i was obtained by subtracting (log-transformed) power during a pre-stimulus reference interval ($Pow_{i\ \mathrm{reference}}$) from (log-transformed) power during the activation interval ($Pow_{i\ \mathrm{activation}}$) according to the formula: $TRP(\log\ Pow_i) = \log\ [Pow_{i\ \mathrm{activation}}] - \log\ [Pow_{i\ \mathrm{reference}}]$. Therefore, decreases in power from the reference to the activation interval are expressed as negative values (i.e. desynchronization), while task-related increases in power (synchronization) are expressed as positive values. $Pow_{i\ \mathrm{activation}}$ and $Pow_{i\ \mathrm{reference}}$ were determined as follows: A 13 s time interval during presentation of the fixation cross served as pre-stimulus reference interval for TRP calculation (see Fig. 1). In the dance improvisation task as well as in the waltz task the whole time period of dancing imagery was used as activation interval. In the AU task, a 1000 ms time window directly before pressing the IDEA-button (1250–250 ms before pressing the IDEA-button) was used as activation interval in EEG analyses (see Fig. 1). For both the reference and the activation periods EEG data were carefully checked for artifacts and artifactual epochs caused by muscle tension, eye blinks or eye movements were excluded from further analyses. In a next step, EEG signals were filtered by applying an FFT filter for the analyzed alpha frequency bands (lower alpha: 8–10 Hz; upper alpha: 10–12 Hz). Subsequently, power estimates were obtained by squaring filtered EEG signals and then band power values (μV^2) were (horizontally) averaged for both the pre-stimulus reference period and the activation intervals. Based on visual inspection of the topographical distribution of TRP, for further analyses, electrode positions were aggregated as following: frontal left (FP_1, AF_3, F_3, F_7), frontal right (FP_2, AF_4, F_4, F_8), frontocentral left (FC_1, FC_5), frontocentral right (FC_2, FC_6), centrotemporal left (C_3, T_3), centrotemporal right (C_4, T_4), centroparietal left (CP_1, CP_5), centroparietal right (CP_2, CP_6), parietotemporal left (P_3, T_5), parietotemporal right (P_4, T_6) parietooccipital left (PO_3, PO_5, O_1), and parietooccipital right (PO_4, PO_6, O_2). The midline electrodes (F_Z, C_Z, P_Z) were not included in the analyses (as we were also interested in potential hemispheric differences).

Procedure

At the beginning of the EEG recording session, two 2-min EEG sequences under resting conditions were recorded, the first with eyes closed, the second with eyes open. Then, after a thorough task instruction (demonstration of tasks, type of responding etc.) the participants started to work on the experimental tasks. The order of task presentation was fixed: Experimental session started with the AU task, followed by the waltz task and finally by the dance improvisation task. In total the EEG recording session took about 1 h. Subsequent to the EEG session participants worked on the NEO-PI-R.

Results

Behavioral results

There were no significant differences between professional dancers and novices with respect to age ($p > 0.05$) and state anxiety during the EEG recording session ($p > 0.05$). Moreover, we observed no significant group differences with respect to the broad Big Five personality dimensions. However, professional dancers tend ($p = 0.053$) to display higher scores on the personality dimension openness to new experiences which is seen in close relation to creativity (e.g. Feist, 1998; King et al., 1996). With respect to the performance of the Alternative Uses task, professional dancers produced a larger number of ideas (i.e. higher ideational fluency, which could be considered as a good index of creativity; cf. Guilford, 1950) than novices did (mean ideational fluency: 15.77 vs. 7.97 in dancers vs. novices, $p < 0.05$).

EEG results

In order to test potential group differences in task-related alpha (de-)synchronization during performance of experimental tasks we computed two ANOVAs for repeated measures (separately for the lower alpha and the upper alpha band) using TASK (improvisation, waltz, AU), HEMISPHERE (left vs. right) and AREA (frontal, frontocentral, centrotemporal, centroparietal, parietotemporal and parietooccipital) as within subjects variables and GROUP (dancers vs. novices) as between subjects variable. In case of violations of sphericity assumptions degrees of freedom were corrected by means of the most conservative Greenhouse Geisser procedure. The probability of a Type I error was maintained at 0.05.

Dealing first with the lower alpha band, we observed a significant main effect AREA, $F\,(1.55, 46.41) = 7.01$, $p < 0.01$, $\eta^2 = 0.19$), indicating an increase in alpha synchronization from frontal to parietooccipital brain regions. The right hemisphere displayed a stronger alpha synchronization than the left hemisphere (main effect HEMISPHERE: $F\,(1, 30) = 4.33$, $p < 0.05$, $\eta^2 = 0.13$). In addition, experimental tasks were associated with different patterns of lower alpha synchronization (see Fig. 2).

The ANOVA yielded a significant main effect TASK ($F\,(1.54, 46.11) = 6.72$, $p < 0.01$, $\eta^2 = 0.18$) with the strongest level of synchronization in the AU, followed by the improvisation and finally by the waltz task. This effect was further moderated by topographical area and hemisphere (TASK × AREA interaction: $F\,(2.76, 82.72) = 4.67$, $p < 0.01$, $\eta^2 = 0.13$; TASK × AREA × HEMISPHERE interaction: $F\,(5.34, 160.31) = 2.52$, $p < 0.05$, $\eta^2 = 0.08$). Accordingly, task differences were most pronounced in frontal, frontocentral and centrotemporal brain regions with the AU task displaying the largest amount of frontal alpha synchronization, followed by the improvisation and finally by the waltz task which exhibited the lowest level of alpha synchronization in frontal brain areas (see Fig. 2). In addition, as it was revealed by an interaction between AREA, TASK and HEMISPHERE, performance of the AU task (as opposed to the improvisation and the waltz task) was

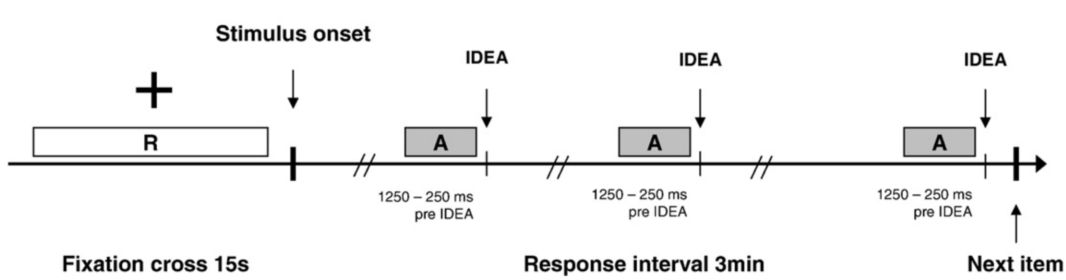


Fig. 1. Schematic time course and measurement intervals of the Alternative Uses task.

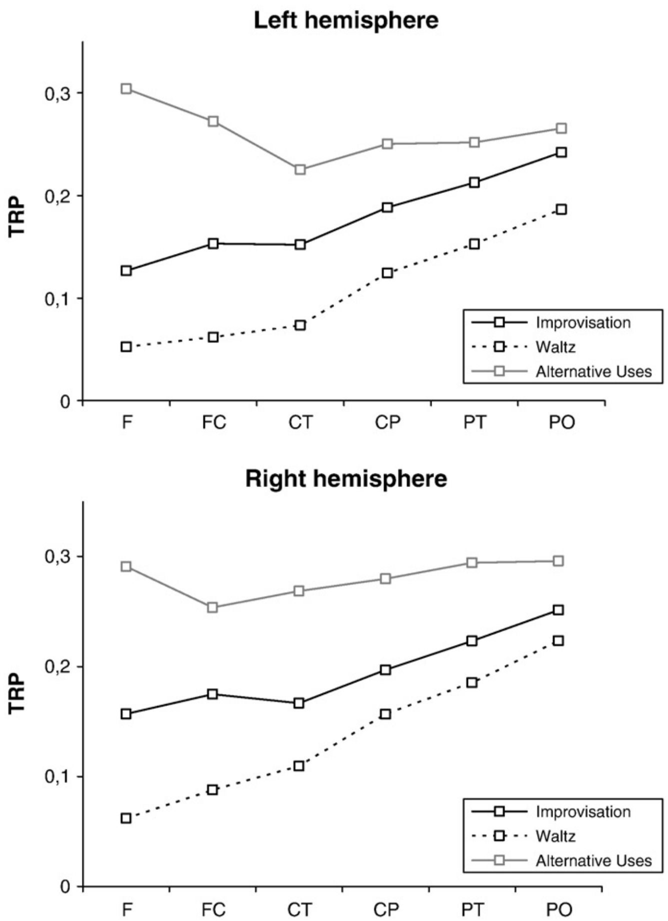


Fig. 2. Task-related changes of EEG alpha band power (TRP) in the lower alpha band (8–10 Hz) during performance of the improvisation, the waltz and the Alternative Uses task separately for the left and the right hemisphere. F: frontal; FC: frontocentral; CT: centrotemporal; CP: centroparietal; PT: parietotemporal; PO: parietooccipital.

associated with a diffuse (i.e. topographically undifferentiated) pattern of alpha synchronization in the right hemisphere. The remaining ANOVA effects in the lower alpha band failed to reach statistical significance.

In the upper alpha band the ANOVA yielded a significant main effect of AREA, F (1.81, 54.44) = 4.65, $p<0.05$, $\eta^2=0.13$), suggesting an increase in alpha synchronization from anterior to posterior regions of the brain. This effect was more pronounced in the right than in the left hemisphere, as it was evident by an interaction HEMISPHERE and AREA, F (2.83, 84.80) = 4.45, $p<0.01$, $\eta^2=0.13$. Similarly to the lower alpha band, the AU task can be also characterized by a comparatively strong upper alpha synchronization in frontal, frontocentral, centrotemporal and centroparietal brain regions, while in the improvisation and in the waltz task considerably lower anterior alpha synchronization was observed (TASK × AREA interaction: F (3.11, 93.26) = 7.34, $p<0.01$, $\eta^2=0.20$). In addition, dancers tend to show higher alpha synchronization in posterior (i.e. centroparietal, parietotemporal and parietooccipital) brain regions than novices. This interaction between AREA and GROUP, however, just failed to reach statistical significance (F (1.81, 54.44) = 3.06, $p=0.06$, $\eta^2=0.09$).

In order to investigate possible group differences in task-related alpha (de-)synchronization during performance of experimental tasks more thoroughly we computed repeated measurement ANOVAs separately for the improvisation, the waltz and the AU task. As effects related to experimental GROUP were more pronounced in the upper alpha band (as compared with the lower alpha band) we focused on this frequency band here. In each of these ANOVAs the variables HEMISPHERE (left vs. right) and AREA (from frontal to parietooccipital) were used as within subjects variables and GROUP (dancers vs. novices) as between subjects variable.

Dealing first with the waltz task we observed a significant main effect of AREA, F (1.68, 50.31) = 5.09, $p<0.05$, $\eta^2=0.15$), suggesting a stepwise increase in alpha synchronization from frontal to parietooccipital brain regions, which was more pronounced in the right than in the left hemisphere (HEMISPHERE × AREA interaction: F (3.22, 96.73) = 2.66, $p<0.05$, $\eta^2=0.08$). In the waltz task we observed no effects related to experimental group.

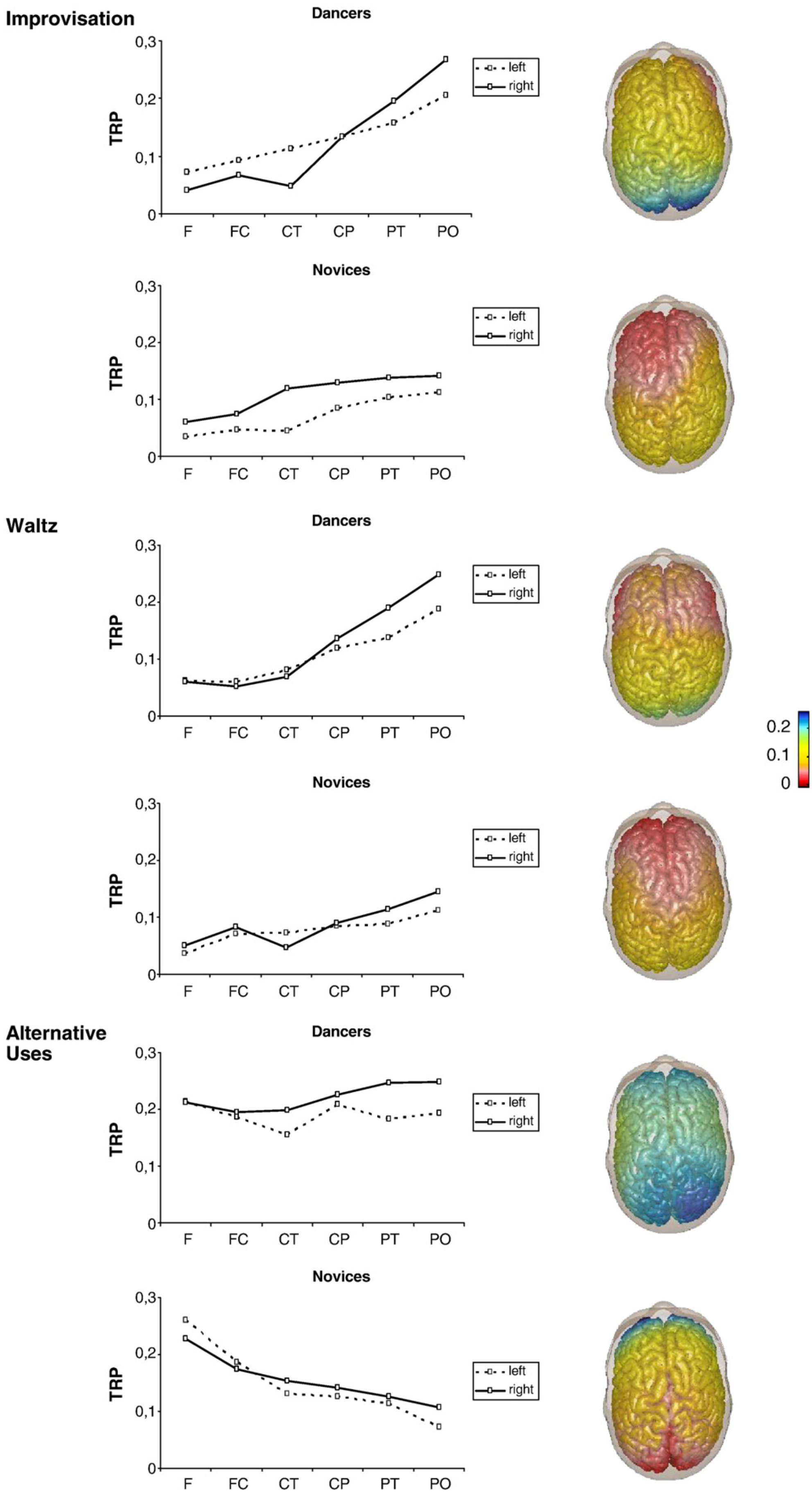
In the improvisation task alpha synchronization increased from anterior to posterior brain regions (main effect of AREA: F (2.00, 60.11) = 9.10, $p<0.01$, $\eta^2=0.23$). In the improvisation task dancers and novices exhibited different patterns of alpha synchronization, as it was suggested by a significant interaction between HEMISPHERE, AREA and GROUP, F (2.38, 71.35) = 2.97, $p<0.05$, $\eta^2=0.09$. The pattern of this interaction is illustrated in Fig. 3. Accordingly, novice dancers display a comparatively low level of alpha synchronization which is somewhat more pronounced in the right than in the left hemisphere and tends to slightly increase from frontal to posterior brain regions. Professional dancers, in contrast, exhibit comparatively strong alpha synchronization in posterior brain regions (particularly in parietotemporal and parietooccipital cortices), especially in the right hemisphere.

In the AU task alpha synchronization tends to decline from frontal to parietooccipital brain regions (i.e. main effect of AREA, F (1.85, 55.44) = 3.52, $p<0.05$, $\eta^2=0.11$). Posterior brain regions of the right hemisphere were again associated with a higher level of alpha synchronization than corresponding regions of the left hemisphere, as it was evident by a significant HEMISPHERE × AREA interaction, F (2.20, 65.87) = 3.22, $p<0.05$, $\eta^2=0.10$. We also observed an interaction between AREA and GROUP in the upper alpha band (F (1.85, 55.44) = 4.42, $p<0.05$, $\eta^2=0.13$). As shown in Fig. 3, professional dancers showed considerably more alpha synchronization in centroparietal, parietotemporal and parietooccipital brain regions than novice dancers did.

Discussion

In this study we investigated EEG alpha activity in professional dancers who have attained a high level of expertise in ballet or modern dance. The group of professional dancers was compared with a group of novices who has only basic experience in dancing and completed no comprehensive training in this domain. The EEG was recorded during the performance of two different dancing imagery tasks which considerably differed with respect to their creative demands. In the dance improvisation task they were instructed to mentally perform a dance which should be as original or creative as possible. Participants were instructed to let their minds free wander and to think of possible dances no one else would think of. Unlike this, in the task with lower creative demands participants were asked to imagine dancing the waltz, a common standard dance which involves a sequence of monotonous steps or movements. In order to ensure comparability with previous studies in this field of research, brain activity was also measured during performance of the Alternative Uses task which is known as a good measure of creativity.

Fig. 3. Task-related changes in EEG alpha band power (TRP) in the upper alpha band (10–12 Hz) during performance of the dance improvisation task, the waltz task and the Alternative Uses task separately for professional dancers and novices. Blue regions in the maps indicate increases in alpha activity relative to rest, red regions unchanged activity or even decreases. F: frontal; FC: frontocentral; CT: centrotemporal; CP: centroparietal; PT: parietotemporal; PO: parietooccipital.


Improvisation
Dancers
Novices
Waltz
Dancers
Novices
Alternative Uses
Dancers
Novices
TRP
0,3
0,2
0,1
0
F
FC
CT
CP
PT
PO
left
right
0.2
0.1
0

Analyses reveal that the generation of alternative uses (in particular the time period directly before the production of an idea) was associated with the strongest level of alpha synchronization, followed by the dance improvisation task and finally by the waltz task. As evident in Fig. 2, these differences were most pronounced in frontal, frontocentral and centrotemporal regions of the brain. Particularly performance of the AU task exhibited a comparatively strong alpha synchronization in frontal brain areas, while performance of the waltz task which involves the lowest creative demands elicited the lowest frontal alpha synchronization. This finding is nicely in agreement with our previous EEG studies on creative cognition which also suggest that performance of this well-known creativity task is (as compared with tasks involving lower creativity-related demands) accompanied by a diffuse and widespread synchronization of alpha activity, which is strongest over frontal brain regions (e.g. Fink et al., 2007, 2009).

The main aim of this study was to compare patterns of alpha synchronization between professional dancers and novices during performance of tasks involving different creative demands. All professional dancers who participated in this study have attained a high level of expertise in this domain. In contrast, the group of novices has completed only a basic course in dancing. Therefore, we can assume that the novices were sufficiently familiar with basic aspects of dancing, in particular familiar enough with the waltz to imagine it appropriately during this study.

As shown in Fig. 3, dancers and novices considerably differed with respect to alpha synchronization during the performance of experimental tasks. While generating alternative uses of conventional objects (i.e. AU task) dancers show stronger alpha synchronization in posterior (i.e. centroparietal, parietotemporal and parietooccipital) brain regions than novice dancers did. Professional dancers generally show a diffuse, widespread and topographically undifferentiated pattern of alpha synchronization, while in the group of novices alpha synchronization is considerably higher in frontal than in posterior brain areas. Given that dancers and novices considerably differed with respect to the number of ideas produced during the performance of this task, we cannot completely rule out the possibility that the observed differences in brain activity might be also (at least partly) due to quantitative differences (i.e. number of responses). However, given that the observed findings in this study largely match those observed in another EEG study of our laboratory in which higher vs. less creative individuals displayed no significant differences in ideational fluency (cf. Fink et al., 2009), pronounced alpha synchronization in posterior brain regions may be also indicative of qualitative information processing rather than merely a result of differences in the number of responses.

During mentally performing a free-associative improvisation dance, professional dancers exhibited more right-hemispheric alpha synchronization in parietotemporal and parietooccipital areas than the group of novices, while during imagining dancing the waltz which involves the lowest creative demands no significant group differences were observed (though dancers show somewhat stronger right-hemispheric alpha synchronization in posterior parietal brain regions than novices, see Fig. 3). Given that the group of dancers was a rather heterogeneous group of dancers (training in classical ballet and/or modern dance) and given that modern dance encourages free-associative dance improvisations, while classical ballet follows pre-establish movements rather than creative improvisations, one might also expect possible differences between these subgroups of dancers. However, an attempt to sub-classify the group of dancers into a "pure" group of classical ballet dancers and into a group of modern dancers (and to investigate potential differences in brain activity between these groups) was unsuccessful, particularly in view of the fact that all dancers who completed a training in ballet had also experience in modern dance and there was no single ballet dancer who exclusively exercises classical ballet dancing.

The debriefing after the EEG session suggests that professional dancers and novices imagined quite similar dances. During performance of the dance improvisation task both groups varied aspects like style, speed and dance position in order to avoid monotony and to produce original dances or sequences of movements. Novices and professional dancers combined different dancing styles, which were sometimes adapted to unusual music (e.g. ballet during Hip-Hop-music). Both groups alternately shifted between slower and faster body movements. With respect to imagining dancing the waltz both groups reported that they were able to imagine this dance appropriately. However, a few of the participants indicated that they had some difficulties to fully concentrate on this dance to the end of the three-minute task performance interval. Taken together, the obtained data of this post-hoc debriefing do not allow for the identification of any obvious differences between novices and experts in different aspects of the imagined movements (such as style, speed or position) and may thus not explain the observed group differences in alpha activity during task performance. Nevertheless, the debriefing data indicate that both novices and dancers were actually engaged in imagining dancing during the EEG testing session. The debriefing data may (at least partly) explain the observed differences in alpha activity between performing the dance improvisation and the waltz task. The finding of more alpha activity during imagining a free-associative dancing task as compared with imagining dancing the waltz may thus not only be due to differences in creative task demands but also due to differences in aspects like intensity or speed of the imagined physical activity.

As outlined in the introduction section, EEG activity in the alpha frequency band has proven to be particularly sensitive to creativity-related demands. Synchronization of alpha has been observed to be more pronounced in higher original than in less original individuals (Fink et al., 2009), or in response to more "free-associative" tasks of creative thinking such as generating unusual uses of everyday objects as opposed to completing suffixes in an original way (Fink et al., 2007). Studies also suggest that more original ideas are associated with stronger alpha activity than less original, conventional ideas (Fink and Neubauer, 2006; Grabner et al., 2007; cf. also Jung-Beeman et al., 2004). Most interestingly, synchronization of alpha has even shown to increase as a result of a creative thinking training (Fink et al., 2006). Nicely in agreement with this evidence the findings of this study also suggest that tasks which allow more free-associative thinking are accompanied by more alpha synchronization than tasks involving lower creative demands. In addition, professional dancers show more alpha synchronization during imagining dancing than novices do. Thus, the findings of this study complement (or extend, respectively) existing evidence on the role of EEG alpha activity in the context of creative thinking.

Alpha synchronization has traditionally been considered as a functional correlate of cortical idling (for review see Klimesch et al., 2007), presumably reflecting a reduced state of active information processing in the underlying neuronal networks (Pfurtscheller et al., 1996). However, meanwhile there is a large body of evidence which indicates that synchronization of alpha activity does not merely reflect cortical deactivation or cortical idling (e.g. Cooper et al., 2003; Jensen et al., 2002; Klimesch et al., 1999, 2007; Ray and Cole, 1985; Sauseng et al., 2005). Contrary to the usual finding that alpha power desynchronizes when individuals are engaged in the performance of cognitively demanding tasks, these studies report synchronization of alpha activity during the performance of different cognitive tasks (e.g. memory, attention etc.). In this context alpha synchronization has been interpreted as a functional correlate of inhibition or top-down control (Sauseng et al., 2005; Klimesch et al., 2007). According to that view, alpha synchronization may reflect an inhibition of cognitive processes that are not directly relevant for task performance (e.g. retrieval of interfering information during a retention interval of a working memory task; Klimesch et al., 2007). Alpha synchronization is especially relevant during internal processing demands, for instance when participants are required to hold information temporarily in mind. Sauseng et al. (2005) report a highly interesting study in this context. The authors observed alpha synchronization in prefrontal brain regions during working memory processing (which requires the active manipulation of information) and they interpreted this finding as reflecting some kind of selective top-down inhibition. Specifically, Sauseng et al. presumed that frontal alpha synchronization could protect working memory processing in executive frontal brain regions against interfering cognitive processes as long as on-going information processing takes place.

Creative thinking certainly involves high internal processing demands. In fact, alpha synchronization during creative thinking could reflect a state of enhanced concentration or alertness of involved brain circuits (cf. Knyazev et al., 2006; see also Knyazev, 2007). In a similar way, the observed alpha synchronization during creative thinking could indicate that information processing in specific brain regions is less likely disturbed by concurrent (task-irrelevant) cognitive processes as long as on-going idea generation occurs. Along these lines we could presume that the observed alpha synchronization in parietooccipital brain regions (which is more pronounced in professional than in novice dancers) could serve as a mechanism responsible for active inhibition or suppression of distracting and interfering information flow from the visual system. This view is also in agreement with Von Stein and Sarnthein (2000) who suggest that alpha activity could reflect the absence of stimulus-driven, external bottom up stimulation and, thus, a form of top-down activity which "is maximal in situations where cortical processes … are driven by free floating associations, mental imagery, planning etc." (p. 311).

Alternatively, the pronounced synchronization of alpha activity in parietooccipital brain regions in professional dancers during mentally creating dances could be also the result of an efficient recruitment of a spatial network where body representations or representations of moving in space are located. However, the observed patterns of brain activity during imagining dancing are almost identical to those observed during the performance of conventional verbal creative thinking tasks. For instance, the Fink et al. (2009) study yields evidence that during the performance of the Alternative Uses task more creative individuals exhibited a comparatively strong hemispheric asymmetry with respect to alpha synchronization in parietal brain regions (with more synchronization in the right than in the left hemisphere). Similarly, in the present study professional dancers showed more right-hemispheric alpha synchronization in parietotemporal and parietooccipital areas than the group of novices during the performance of the free-associative dance improvisation task. Also, when engaged in the Alternative Uses task professional dancers displayed more parietal alpha synchronization than novices did (see Fig. 3).

These findings therefore suggest that the observed patterns of brain activation during creative thinking, particularly the pronounced alpha synchronization in parietal brain regions are due to the creative style in general, and that they are less specific to the employed creative thinking tasks.

In conclusion, the findings obtained here show that it might be a worthwhile enterprise to extend the neuroscientific study of creative thinking towards the investigation of diverse groups of professionals who are engaged in various forms of creative achievement, be it artistic, scientific or even in economic/managerial settings. Specifically, future research in the nascent field of creativity would benefit from studies which aim at identifying personality and brain characteristics that are specific to creative people in general or to creative people of a particular profession, respectively. In this particular context it would be also useful to include a broad range of measures for the assessment of personality and intelligence along with scales for the assessment of relevant sociodemographic and biographical variables (education, family background, critical life events etc.). The inclusion of measures for the assessment of general or specific mental abilities appears to be especially important inasmuch as intelligence and creativity have been observed to be associated on the behavioral level (Barron and Harrington, 1981) and on the neurophysiological level as well (Fink and Neubauer, 2006; Jaušovec, 2000). Also, there is a large body of evidence indicating intelligence-related effects on EEG alpha activity (e.g. Jaušovec, 1996; Neubauer et al., 2006). The assessment of intellectual ability in neuroscientific studies of creative cognition would therefore allow for investigating whether or to which extent any differences in brain activity between different creativity groups are actually due to creativity or (and, respectively) to possible differences in intellectual ability.

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