Review Article

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The Neuroscience of Creativity

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Abstract: While earlier neuroscience studies on creativity have been criticized due to their heterogeneity of findings, recent studies in this field have converged to some common practices and methodological approaches, which have greatly contributed to enhance both the reliability and reproducibility of findings in this field. Relevant neuroscience findings suggest that creative cognition requires a conglomerate of neurocognitive processes involving executive functions, memory processes, internally-focused attention, or spontaneous modes of thought. Studies investigating creativity in more naturalistic, real-life settings reveal some overlap with conventional creative ideation, but also indicate that creativity and its underlying neural mechanisms are specific to the particular domain. Another trend in the neuroscience of creativity is concerned with approaches to enhance creativity, involving a broad diversity of interventions ranging from cognitively-oriented techniques to interventions using physical activity.

Keywords: EEG; fMRI; functional connectivity; creative cognition; divergent thinking

Zusammenfassung: Frühere Studien im Bereich der neurowissenschaftlichen Kreativitätsforschung wurden oft wegen ihrer heterogenen Befunde kritisiert. In der Zwischenzeit haben sich aber einheitlichere Vorgangsweisen in der methodisch-praktischen Durchführung der Studien etabliert, die zur besseren Replizierbarkeit der Befunde beigetragen haben. Einschlägigen Befunden zufolge lässt sich kreatives Denken als Konglomerat von exekutiven Funktionen, Gedächtnisfunktionen, Aufmerksamkeitsprozessen und spontanen Denkprozessen charakterisieren. Studien in alltagsnäheren Kreativitätsdomänen legen einige Überlappungen mit konventionellen kreativen Denkmustern nahe, weisen allerdings auch darauf hin,

dass Kreativität und ihre neuronalen Grundlagen spezifisch für die Domäne sind. Neuere Trends in diesem Forschungsbereich beschäftigen sich auch mit Möglichkeiten zur Förderung der Kreativität, wobei hier ein breites Spektrum von kognitiv-orientierten Techniken bis hin zu Sportinterventionen zum Einsatz kommt.

Schlüsselwörter: EEG; fMRI; Funktionelle Konnektivität; Kreative Kognition; Divergentes Denken

Creativity is commonly defined as the ability to produce work that is novel, original and useful within a certain socio-cultural context (Diedrich et al., 2015; Runco & Jaeger, 2012; Stein, 1953). It is the engine of any progress in culture, science and education, likewise in the economical or industrial domain. From a more personal perspective, creativity has been considered as a sign of mental health and emotional well-being (Simonton, 2000), and might even have the promising potential to heal suffering (Forgeard, 2019). It is hence not surprising that creativity is increasingly attracting attention also in scientific investigations, involving a broad range of different disciplines such as economics, engineering, psychology and most recently, the field of neurosciences. In the last decade, more than 850 studies dealing with *creativity* and the *brain* were published (source: Clarivate Analytics © Web of Science), thereby tripling the number of neuroscience studies on creativity published relative to the century before. Along with the rapidly growing availability of modern brain imaging methods, this vivid research interest may be primarily attributed to continuous advancements in psychometric assessment of the different facets of creativity (Barbot, 2018; Benedek et al., 2013; Reiter-Palmon et al., 2019; Vartanian et al., 2019). Progress in the psychometric/behavioral creativity research tradition has, in turn, stimulated the development of ever more sophisticated experimental tasks and paradigms for assessing the manifold ways of how the brain works while engaged in performance of creativity-related tasks (Benedek et al., 2019).

Creativity is a multifaceted construct involving manifold processes and conditions (Simonton, 2000). A prominent example for this notion is Amabile's (1983; see also Amabile, 2013) componential theory of creativity.

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In this theory, creativity is conceptualized as a function of domain-relevant skills, creativity-relevant processes, task motivation, and social-environmental variables. Domain-relevant skills include expertise, factual knowledge, technical skills, and talent in the respective creativity domain. Creativity-relevant processes involve cognitive styles and personality characteristics that support novel ways of thinking. Task motivation involves intrinsic motivation, i.e. the motivation to engage in a task or to work, since it is interesting and personally challenging. And finally, creativity also depends on factors or conditions of the (social) environment that can either block or stimulate creativity (e.g., excessive time pressure, or sense of positive challenge in the work; Amabile, 2013). Neuroscience studies on creativity are particularly concerned with investigating the cognitive processes implicated in creativity, commonly referred to as creative cognition (Ward, 2007). The investigation of neurocognitive processes involved in creative idea generation or in divergent thinking (i.e. generating different creative solutions to open-ended problems), and in creative problem solving or insight problem solving can be considered as prototypical examples for research in this field (Benedek & Fink, 2018). The most widely used divergent thinking task (Alternative Uses Task), for example, requires people to generate as many and as original uses for everyday objects. The outcomes measured from such tasks, including ideational fluency (number of generated ideas), flexibility of thinking (number of different categories of ideas), and the originality/novelty of the generated ideas, are considered as reliable estimates of creative potential (Runco & Acar, 2012). Tasks for the assessment of insightful problem solving often require a reframing or restructuring of existing mental representations, which is often associated with the subjective experience of a sudden breakthrough (experience of “AHA”; Bowden et al., 2005; Kounios & Beeman, 2009; Sandkühler & Bhattacharya, 2008). For instance, in the compound remote associates task, three stimulus words are presented (e.g., boot, summer, ground) and participants are required to find a word that forms a compound (“camp”) between the three stimulus words (example taken from Bowden et al., 2005).

In the vast majority of neuroscience studies on creativity, brain activity during creative task performance is measured by means of functional magnetic resonance imaging (fMRI) or electroencephalography (EEG). In this particular context, creativity research in the neuroscientific laboratory is often faced with critical task constraints, which make neuroscience studies on creativity often very tricky and challenging. For instance, people are required to be creative while lying supine in a noisy fMRI scanner,

or while their heads are wired with electrodes in special electrode caps. Even more importantly, creative activities such as story writing, dancing, painting a picture, or composing a piece of music etc. are not directly transferable to the neuroscientific laboratory. Therefore, studies must decompose a complex, multi-componential creative activity into smaller, more isolated (and thus more measurable) neurocognitive processes that reflect the respective creativity domain to the best possible extent. In the context of dancing, for example, researchers could require their participants to think of an original improvisation dance and compare the resulting brain activity to that measured while thinking of monotonous sequences of movement (e.g., dancing the waltz; Fink et al., 2009). Similarly, since writing or drawing with a pen would hinder reliable fMRI or EEG assessments (artefacts due to motor activity), studies often ask their participants to think of creative ideas in a predefined thinking period, and subsequently to verbally express the ideas generated (Benedek et al., 2019; Fink et al., 2007; Rominger et al., 2018; in Figure 1 an example adopting this procedure is given). The registration and subsequent quantitative and qualitative assessment of responses during performance of the creativity task, is essential to investigate brain activation in relation to creative performance. Benedek et al. (2019) have recently provided a literature overview of how studies successfully meet the manifold constraints imposed by cognitive neuroscience research. In this particular context, studies converged to some common practices and methodological approaches, which have contributed greatly to increase both the reliability of fMRI and EEG assessments, and the reproducibility of findings in the field of creativity. This includes, inspired by the behavioral/psychometric creativity research tradition, the use of empirically-tested and psychometrically-sound experimental tasks for assessing creative cognition in the neuroscientific laboratory (Benedek et al., 2019). Furthermore, in order to avoid contaminations with response-related motor activity, neuroscience studies in the field of creativity use clever paradigms, which isolate the creativity-related processes of interest and also separate the stages of creative thought processes from stages of responding. And finally, studies assess both qualitative and quantitative indicators of creative task performance during EEG and fMRI assessment, facilitating an analysis of the relationship between functional patterns of brain activity and creative performances.

Neurocognitive Mechanisms Underlying Creativity

Neuroscience research on creativity has provided exciting insights on how the brain produces creative thought (Abraham, 2018). Perhaps the most important finding in this field is the fact that creative cognition is associated with activity patterns in widespread neural networks supporting executive functions (e.g., fluency, flexibility of thinking, inhibition of prepotent responses, etc.), memory processes, internally-focused attention, or spontaneous modes of thought (e.g., Beaty et al., 2019; Boccia et al., 2015; Fink & Benedek, 2014; Gonen-Yaacovi et al., 2013). Essentially, relevant neuroscience findings clearly indicate that creative cognition requires a conglomerate of neurocognitive processes that could be well integrated into “normal” cognition (Benedek & Fink, 2019). For example, envisioning possible improvements to products, requires memory processes to build novel representations of these products, sustained internally-oriented attention to guide active imagination, and vigorous executive control to realize effective and useful task solutions by evaluating/elaborating preliminary thinking results, and by inhibiting prepotent/conventional responses.

Another important finding in this context is that more creative people seem to be characterized by stronger functional connectivity between different creativity-related neural circuits, possibly indicating that higher creative ability is linked with an ability to simultaneously recruit different brain circuits to a greater degree than in less creative people (Beaty et al., 2018a). Specifically, creative thinking has been associated with an increased functional connectivity between default and executive brain networks, potentially reflecting the interplay between generative and evaluative thinking processes (Beaty et al., 2016, 2018b). This is a particularly remarkable finding, as these large-scale brain networks act in opposition in most other cognitive tasks. For example, during goal-directed cognition, such as working memory processing, the executive network exhibits increased activation, while there is deactivation in the default mode network, putatively indicating the attenuation of task-irrelevant mental activity (Anticevic et al., 2012; Beaty et al., 2016). Similarly, Rominger et al. (2019) measured transient phase-locking between neuroelectrical signals at different cortical sites (as introduced in Lachaux et al., 1999) and found that, during the creative thinking process, people who generated more creative ideas showed a more rapid increase in functional connectivity between frontal and parietal-occipital sites, putatively indicating more effective executive processes. This

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Figure 1: Schematic time course of a trial of the soccer decision-making task during EEG and fMRI assessment (taken from Fink et al., 2018; <https://doi.org/10.1016/j.neuropsychologia.2018.04.025>). A trial started with presentation of a fixation cross for 10 s (assessment of brain activity during a pre-stimulus baseline). Afterwards brief video clips of naturalistic soccer decision-making situations are shown (ranging from 2 to 12 s). During the idea generation period, a fixed image of the soccer scene remains visible on the screen, signalling 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 (bulb switched on) while maintaining the target orientation (i. e., scoring a goal) in mind. When a participant 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.). Oral responses were recorded via microphone and transcribed for further analyses.

study adds important evidence to support the notion that temporal dynamics of neuro-cognitive functions across the creative thinking process also affect the quality (i. e., creativity) of the outcome.

Trends in Research on the Neuroscience of Creativity

Recent studies in the field of creativity and neuroscience are also concerned with the investigation of brain activity patterns during everyday real-life creativity tasks. For example, some studies have investigated brain activity patterns while participants were required to be creative in affective contexts, i. e. to generate reappraisals to self-relevant negative emotional events (Fink et al., 2017; Papousek et al., 2017; Perchtold et al., 2018). Participants were required to generate reappraisals of given anger-eliciting situations (as many and as different as possible), in such a

way that reduces anger, which naturally arises when confronted with these scenarios. Cognitive reappraisal is regarded as an effective strategy to cope with adverse events (e. g., Augustine & Hemenover, 2009; Webb et al., 2012), representing a promising, non-pharmacological resource to improve psychological health and well-being (Gross & John, 2003). As in conventional creative ideation, cognitive reappraisal requires the generation of alternative, but useful, and effective solutions to an open-ended problem. It further requires people to flexibly adopt and to generate new perspectives, solutions or strategies, and to override the typical and most obvious responses elicited by this situation (e. g. experience of anger). Such flexible idea production is likewise seen in many other creativity-related tasks, and in fact, both fluency and flexibility of cognitive reappraisal have been found to be significantly and positively associated with conventional divergent thinking measures and with openness, which is closely linked to creativity (Weber et al., 2014). In line with this, neuroscientific findings indicated that cognitive reappraisal was

generally associated with a similar pattern of brain activity as conventional creative ideation (Fink et al., 2017; Perchtold et al., 2018). As expected, some important differences were found between cognitive reappraisal and conventional creative ideation. Specifically, cognitive reappraisal (vs. conventional creative ideation) was associated with a more intense involvement of executive processes, necessary to regulate an ongoing negative emotional state, in addition to processes involved in conventional creative ideation (Fink et al., 2017). Furthermore, Perchtold et al. (2018) found that cognitive reappraisal was, among others, also associated with brain networks implicated in social cognition.

Another example where creativity and neuroscience studies involve real-life demands is research in the athletic domain of soccer. Successful solutions in soccer game situations are often original and surprising. Soccer players need to focus their attention on specific conditions of the soccer scenario (positions of teammates and opponents), to anticipate the behavior of other players, and to think of possible passes or moves that are most promising to score a goal. The imagination of creative moves also involves search and retrieval of task-relevant information stored in

memory (e. g., soccer-specific rules, technical knowledge about the execution of a pass or move, trained standard situations, etc.). Additionally, in order to generate a creative and effective move, soccer players are required to evaluate the efficacy and appropriateness of an imagined move, and to inhibit inappropriate, potentially less successful solution approaches. Creative solutions in sport situations thus seem to be characterized by mechanisms that are very similar to those seen in other creativity-related domains (e. g., Rasmussen & Østergaard, 2016; Roca et al., 2018; for overview see Memmert, 2015). Based on these assumptions, some studies have therefore investigated neurocognitive mechanisms associated with creative solutions in naturalistic soccer decision-making situations (Fink et al., 2018, 2019).

In these studies, soccer players (from hobby to amateur) were presented brief video clips of real soccer decision-making situations (ranging from 2s to 12s in length). After the image was frozen they were asked to imagine themselves as the acting player of the attacking team, and depending on the respective task instruction, to think either of a creative/original (possible and promising), or an obvious/conventional move (control

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condition), that might lead to a goal. Performance of the soccer decision-making task was associated with comparatively strong decreases in EEG alpha power (relative to a pre-stimulus baseline) at parietal and occipital sites, indicating high visuospatial processing demands during the processing of the complex soccer scenarios (Fink et al., 2018). Interestingly, more creative performance in the soccer task was associated with stronger alpha power reduction over left cortical sites, primarily involving motor-related areas. This finding suggests that individuals who generated more creative moves were more intensively engaged in processes related to motor or movement imagery. Similarly, findings from an fMRI study (Fink et al., 2019) revealed that variations in soccer-specific creativity were associated with brain activity in a mainly left-lateralized network of brain regions, which support various cognitive functions such as semantic information processing, visual and motor imagery, as well as the processing and integration of sensorimotor and somatosensory information. Taken together, these EEG (Fink et al., 2018) and fMRI (Fink et al., 2019) studies revealed that imagining creative soccer moves is a complex cognitive process, involving multimodal input from different sensory, motor and perceptual sources. These studies also provide evidence for the notion that neural underpinnings of creativity differ across domains (e.g., Baer, 1998; Boccia et al., 2015). Furthermore, these studies also support evidence from the behavioral research domain, which highlights the crucial role of cognitive and executive functions in successful soccer performance (e.g., Scharfen & Memmert, 2019; Vestberg et al., 2017). Nevertheless, additional research is needed to delineate the manifold neurocognitive processes (e.g. imagery, attention, visual and sensorimotor information processing) implicated in this domain, and to assess how these processes contribute to the generation of creative solutions in soccer.

Conclusion

Earlier neuroscience studies of creativity have been criticized due to their diversity and inconsistency of findings (Dietrich & Kanso, 2010), showing only “little clear evidence of overlap” (Arden et al., 2010, p. 143). This inconsistency has been traced back to the variegated and multi-componential nature of creativity, as well as to the diversity of methodological approaches used (Fink & Benedek, 2014). However, in the last decade considerable progress in the development of psychometric and laboratory creativity tasks has been made. In fact, neuroscien-

tific studies on creativity have since converged to some common practices and approaches, which have greatly contributed to enhance reliability and reproducibility of findings in the neuroscience of creativity (Benedek et al., 2019).

Recent neuroscience studies on creativity have taken a step further by investigating creativity in more natural settings involving ecologically valid tasks (e.g. creativity in an affective context: Perchtold et al., 2018; creativity in soccer: Fink et al., 2018; or musical improvisation: Bengtsson et al., 2007). Findings therein have suggested some overlap with brain activity patterns during conventional creative ideation and also indicated that creativity and its underlying neural mechanisms are specific to a particular domain (e.g., Boccia et al., 2015; Fink et al., 2018; Rominger et al., 2018). Finally, another exciting trend in the neuroscience of creativity is concerned with approaches to enhance creativity, involving a broad diversity of interventions ranging from cognitively-oriented techniques (e.g., Sun et al., 2016) to interventions of physical activity such as walking (Oppezzo & Schwartz, 2014) or cycling (Colzato et al., 2013). In light of the high plasticity of the brain towards learning or training (e.g. Weber et al., 2019), and given the importance of creativity in almost all aspects of daily life, future creativity research will be particularly challenged to address the question of how creative abilities can be realized to their best possible extent.

References

- Abraham, A. (2018). *The neuroscience of creativity*. Cambridge, UK: Cambridge University Press.
- Amabile, T.M. (1983). The social psychology of creativity: A componential conceptualization. *Journal of Personality and Social Psychology* 45(2), 357–376.
<http://dx.doi.org/10.1037/0022-3514.45.2.357>
- Amabile, T.M. (2013). Componential theory of creativity. In E.H. Kessler (Ed.), *Encyclopedia of management theory* (Vol. 1, pp. 135–139). Thousand Oaks, SAGE Publications, Ltd. doi: 10.4135/9781452276090.n50
- Anticevic, A., Cole, M. W., Murray, J. D., Corlett, P. R., Wang, X. J., & Krystal, J. H. (2012). The role of default network deactivation in cognition and disease. *Trends in Cognitive Sciences* 16(12), 584–592. doi:10.1016/j.tics.2012.10.008
- Arden, R., Chavez, R.S., Grazioplene, R., Jung, R.E., 2010. Neuroimaging creativity: a psychometric review. *Behavioural Brain Research* 214, 143–156. <https://doi.org/10.1016/j.bbr.2010.05.015>
- Augustine, A. A., & Hemenover, S. H. (2009). On the relative effectiveness of affect regulation strategies: A meta-analysis. *Cognition and Emotion* 23, 1181–1220. doi:10.1080/02699930802396556

- Baer, J. (1998). The case for domain specificity of creativity. *Creativity Research Journal* 11, 173–177. doi: https://doi.org/10.1207/s15326934crj1102_7
- Barbot, B. (2018). The Dynamics of Creative Ideation: Introducing a New Assessment Paradigm. *Frontiers in Psychology* 9, 2529. doi: [10.3389/fpsyg.2018.02529](https://doi.org/10.3389/fpsyg.2018.02529)
- Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative cognition and brain network dynamics. *Trends in Cognitive Sciences* 20(2), 87–95. <https://doi.org/10.1016/j.tics.2015.10.004>
- Beaty, R., Kenett, Y.N., Christensen, A.P., Rosenberg, M.D., Benedek, M., Chen, Q., Fink, A., Qiu, J., Kwapił, T.R., Kane, M., & Silvia, P. (2018a). Robust Prediction of Individual Creative Ability from Brain Functional Connectivity. *Proceedings of the National Academy of Sciences, PNAS* 115(5), 1087–1092. <https://doi.org/10.1073/pnas.1713532115>
- Beaty, R.E., Seli, P. & Schacter, D.L. (2019). Network neuroscience of creative cognition: mapping cognitive mechanisms and individual differences in the creative brain. *Current Opinion in Behavioral Sciences* 27, 22–30. <https://doi.org/10.1016/j.cobeha.2018.08.013>
- Beaty, R. E., Thakral, P. P., Madore, K. P., Benedek, M., & Schacter, D. L. (2018b). Core network contributions to remembering the past, imagining the future, and thinking creatively. *Journal of Cognitive Neuroscience* 30(12), 1939–1951. https://doi.org/10.1162/jocn_a_01327
- Benedek, M. & Fink, A. (2019). Toward a neurocognitive framework of creative cognition: the role of memory, attention, and cognitive control. *Current Opinion in Behavioral Sciences* 27, 116–122. <https://doi.org/10.1016/j.cobeha.2018.11.002>
- Benedek, M., Christensen, A.P., Fink, A. & Beaty, R. (2019). Creativity Assessment in Neuroscience Research. *Psychology of Aesthetics, Creativity, and the Arts* 13, 218–226. <http://dx.doi.org/10.1037/aca0000215>
- Benedek, M., Mühlmann, C., Jauk, E. & Neubauer, A. C. (2013). Assessment of Divergent Thinking by means of the Subjective Top-Scoring Method: Effects of the Number of Top-Ideas and Time-on-Task on Reliability and Validity. *Psychology of Aesthetics, Creativity, and the Arts* 7(4), 341–349. doi:10.1037/a0033644
- Bengtsson, S. D., Csíkszentmihályi, M., & Ullén, F. (2007). Cortical regions involved in the generation of musical structures during improvisation in pianists. *Journal of Cognitive Neuroscience* 19, 830–842. doi:10.1016/j.neuroimage.2009.08.042
- 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. *Frontiers in Psychology* 6, 1195. doi: [10.3389/fpsyg.2015.01195](https://doi.org/10.3389/fpsyg.2015.01195)
- Bowden, E.M., Beeman, M., Fleck, J., & Kounios, J. (2005). New approaches to demystifying insight. *Trends in Cognitive Sciences* 9(7), 322–328. <https://doi.org/10.1016/j.tics.2005.05.012>
- Colzato, L.S., Szapora, A., Pannekoek, J.N., & Hommel, B. (2013). The impact of physical exercise on convergent and divergent thinking. *Frontiers in Human Neuroscience* 7, 824. <https://doi.org/10.3389/fnhum.2013.00824>

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- Diedrich, J., Benedek, M., Jauk, E., & Neubauer, A. C. (2015). Are creative ideas novel and useful? *Psychology of Aesthetics, Creativity, and the Arts* 9(1), 35–40. <http://dx.doi.org/10.1037/a0038688>
- Dietrich, A., Kanso, R., 2010. A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological Bulletin* 136, 822–848. doi: 10.1037/a0019749
- Fink, A., & Benedek, M. (2014). EEG alpha power and creative ideation. *Neuroscience and Biobehavioral Reviews* 44, 111–123. doi:10.1016/j.neubiorev.2012.12.002
- Fink, A., Bay, J.U., Koschutnig, K., Prettenhaler, K., Rominger, C., Benedek, M., Papousek, I., Weiss, E.M., Seidel, A., & Memmert, D. (2019). Brain and soccer: Functional patterns of brain activity during the generation of creative moves in real soccer decision-making situations. *Human Brain Mapping* 40, 755–764. <https://doi.org/10.1002/hbm.24408>
- Fink, A., Benedek, M., Grabner, R. H., Staudt, B., & Neubauer, A. C. (2007). Creativity meets neuroscience: Experimental tasks for the neuroscientific study of creative thinking. *Methods* 42, 68–76. doi:10.1016/j.ymeth.2006.12.001
- 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. doi:10.1016/j.neuroimage.2009.02.036
- Fink, A., Rominger, C., Benedek, M., Perchtold, C., Papousek, I., Weiss, E.M., Seidel, A., & Memmert, D. (2018). EEG alpha activity during imagining creative moves in soccer decision-making situations. *Neuropsychologia* 114, 118–124. <https://doi.org/10.1016/j.neuropsychologia.2018.04.025>
- Fink, A., Weiss, E.M., Schwarzl, U., Weber, H., Loureiro de Assunção, V., Rominger, C., Schuster, G., Lackner, H.K., Papousek, I. (2017). Creative Ways to Well-being: Reappraisal Inventiveness in the Context of Anger Evoking Situations. *Cognitive, Affective, and Behavioral Neuroscience* 17, 94–105. doi: 10.3758/s13415-016-0465-9
- Forgeard, M. (2019). Creativity and healing. In: James C. Kaufman & Robert J. Sternberg (Eds.), *The Cambridge Handbook of Creativity* (pp. 319–332). UK, Cambridge University Press.
- 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. *Frontiers in Human Neuroscience* 7, 465. doi:10.3389/fnhum.2013.00465
- Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and wellbeing. *Journal of Personality and Social Psychology* 85, 348–362. doi:10.1037/0022-3514.85.2.348
- Jung, R. E., & Vartanian, O. (2018). *The Cambridge handbook of the neuroscience of creativity*. Cambridge, UK: Cambridge University Press.
- Kounios, J., & Beeman, M. (2009). The Aha! Moment: The Cognitive Neuroscience of Insight. *Current Directions in Psychological Science* 18(4), 210–216. <https://doi.org/10.1111/j.1467-8721.2009.01638.x>
- Lachaux, J.-P., Rodriguez, E., Martinerie, J., & Varela, F. J. (1999). Measuring phase synchrony in brain signals. *Human Brain Mapping* 8, 194–208. [https://doi.org/10.1002/\(SICI\)1097-0193\(1999\)8:4<194::AID-HBM4>3.0.CO;2-C](https://doi.org/10.1002/(SICI)1097-0193(1999)8:4<194::AID-HBM4>3.0.CO;2-C)
- Memmert, D. (2015). *Teaching tactical creativity in sport: Research and practice*. Abingdon, England: Routledge.
- Oppezzo, M., & Schwartz, D.L. (2014). Give your ideas some legs: The positive effect of walking on creative thinking. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 40, 1142–1152. <https://doi.org/10.1037/a0036577>
- Papousek, I., Weiss, E.M., Perchtold, C.M., Weber, H., Loureiro de Assunção, V., Schuster, G., Lackner, G., & Fink, A. (2017). The capacity for generating cognitive reappraisals is reflected in asymmetric activation of frontal brain regions. *Brain Imaging and Behavior* 11, 577–590. doi:10.1007/s11682-016-9537-2
- Perchtold, C., Papousek, I., Koschutnig, K., Rominger, C., Weber, H., Weiss, E.M., & Fink, A. (2018). Affective creativity meets classic creativity in the scanner. *Human Brain Mapping* 39, 393–406. doi: 10.1002/hbm.23851
- Rasmussen, L.J.T., & Østergaard, L.D. (2016). The Creative Soccer Platform: New Strategies for Stimulating Creativity in Organized Youth Soccer Practice. *Journal of Physical Education, Recreation & Dance* 87 (7), 9–19. <https://doi.org/10.1080/07303084.2016.1202799>
- Reiter-Palmon, R., Forthmann, B., & Barbot, B. (2019). Scoring divergent thinking tests: A review and systematic framework. *Psychology of Aesthetics, Creativity, and the Arts*, 13(2), 144–152. <http://dx.doi.org/10.1037/aca0000227>
- Roca, A., Ford, P.R., & Memmert, D. (2018). Creative decision making and visual search behavior in skilled soccer players. *PLOS ONE* 13 (7): e0199381. <https://doi.org/10.1371/journal.pone.0199381>
- Rominger, C., Papousek, I., Perchtold, C., Benedek, M., Weiss, E., Schwerdtfeger, A. & Fink, A. (2019). Creativity is associated with a characteristic U-shaped function of alpha power changes accompanied by an early increase of functional coupling. *Cognitive, Affective, and Behavioral Neuroscience*. <https://doi.org/10.3758/s13415-019-00699-y>
- 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* 118, 13–19. <https://doi.org/10.1016/j.neuropsychologia.2018.02.013>
- Runco, M.A., & Acar, S. (2012). Divergent thinking as an indicator of creative potential. *Creativity Research Journal* 24(1), 66–75. <http://dx.doi.org/10.1080/10400419.2012.652929>
- Runco, M. A., & Jaeger, G. J. (2012). The standard definition of creativity. *Creativity Research Journal* 24(1), 92–96. <https://doi.org/10.1080/10400419.2012.650092>
- Sandkühler, S., & Bhattacharya, J. (2008). Deconstructing Insight: EEG Correlates of Insightful Problem Solving. *PLOS ONE* 3(1): e1459. <https://doi.org/10.1371/journal.pone.0001459>
- Scharfen, H-E, & Memmert, D. (2019). Measurement of cognitive functions in experts and elite athletes: A meta-analytic review. *Applied Cognitive Psychology*. <https://doi.org/10.1002/acp.3526> [published ahead of print]
- Simonton, D.K. (2000). Creativity. Cognitive, personal, developmental, and social aspects. *American Psychologist* 55, 151–158. <http://dx.doi.org/10.1037/0003-066X.55.1.151>
- Stein, M.I. (1953). Creativity and Culture. *The Journal of Psychology* 36, 311–322. <https://doi.org/10.1080/00223980.1953.9712897>

- Sun, J., Chen, Q., Zhang, Q., Li, Y., Li, H., Wei, D., ... & Qiu, J. (2016). Training your brain to be more creative: Brain functional and structural changes induced by divergent thinking training. *Human Brain Mapping* 37, 3375–3387. <https://doi.org/10.1002/hbm.23246>
- Vartanian, O., Beatty, E.L., Smith, I., Forbes, S., Rice, E., & Crocker, J. (2019). Measurement matters: the relationship between methods of scoring the Alternate Uses Task and brain activation. *Current Opinion in Behavioral Sciences* 27, 109–115. <https://doi.org/10.1016/j.cobeha.2018.10.012>.
- Vestberg, T., Reinebo, G., Maurex, L., Ingvar, M., & Petrovic, P. (2017). Core executive functions are associated with success in young elite soccer players. *PLOS ONE* 12(2): e0170845. <https://doi.org/10.1371/journal.pone.0170845>
- Ward, T.B. (2007). Creative cognition as a window on creativity. *Methods* 42, 28–37. <https://doi.org/10.1016/j.ymeth.2006.12.002>.
- Webb, T. L., Miles, E., & Sheeran, P. (2012). Dealing with feeling: A meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. *Psychological Bulletin* 138, 775–808. doi: 10.1037/a0027600
- Weber, B., Koschutnig, K., Schwerdtfeger, A., Rominger, C., Papousek, I., Weiss, E.M., Tilp, M., & Fink, A. (2019). Learning Unicycling Evokes Manifold Changes in Gray and White Matter Networks Related to Motor- and Cognitive Functions. *Scientific Reports*, 9(1):4324. <https://doi.org/10.1038/s41598-019-40533-6>
- Weber, H., Loureiro de Assunção, V., Martin, C., Westmeyer, H., & Geisler, F. C. (2014). Reappraisal inventiveness: The ability to create different reappraisals of critical situations. *Cognition & Emotion* 28, 345–360. doi:10.1080/02699931.2013.832152

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