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A bio-psycho-behavioral model of creativity

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In this article, a model of creativity is proposed that seeks to integrate concepts and findings from different lines of creativity research. The model aims to provide an understanding of interindividual differences in real-life creative behavior by considering central psychological constructs, their mutual relationships, and their respective neurobiological bases. It is argued that openness to experience, cognitive creative potential (divergent thinking ability), and intelligence constitute core variables relevant to real-life creativity across domains. Interindividual differences in these variables are thought to arise from variation in the dopaminergic system, the default mode, and the executive control network. The model may guide future research in that it provides an integrative framework for the study of human creativity at multiple levels of analysis.

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Creativity and creative individuals are of inherent fascination. Each of us has a unique and personal understanding of what they might consider creative, and so we all come up with different concepts when asked ‘what do you associate with *creativity*?’. These associations range from adjectives referring to ideas or products (such as ‘original’ or ‘innovative’) to characteristics of people’s personality (‘open-minded’, ‘spontaneous’), intellectual ability (‘clever’, ‘gifted’), or motivation (‘enthusiastic’). Also, associations to creativity encompass traits that point to mental disorder (‘schizotypal’) or spontaneous thought (‘being kissed by the muse’). All of these concepts have been subject to the empirical study of creativity, an all of them can be related to some aspect of the complex phenomenon.

In this article, a model is proposed that seeks to integrate concepts and findings from different fields of creativity research. Building upon prior work on the prediction of real-life creative behavior across various domains of creative endeavor [1], the model presented here extends this work to three levels of analysis: (I) neurobiological systems that are thought to underlie (II) individual differences in creativity-related psychological personality and ability dimensions, and lastly (III) real-life creative behavior (see Figure 1). The hierarchical structure indicates that variables at higher levels build upon those on lower levels.

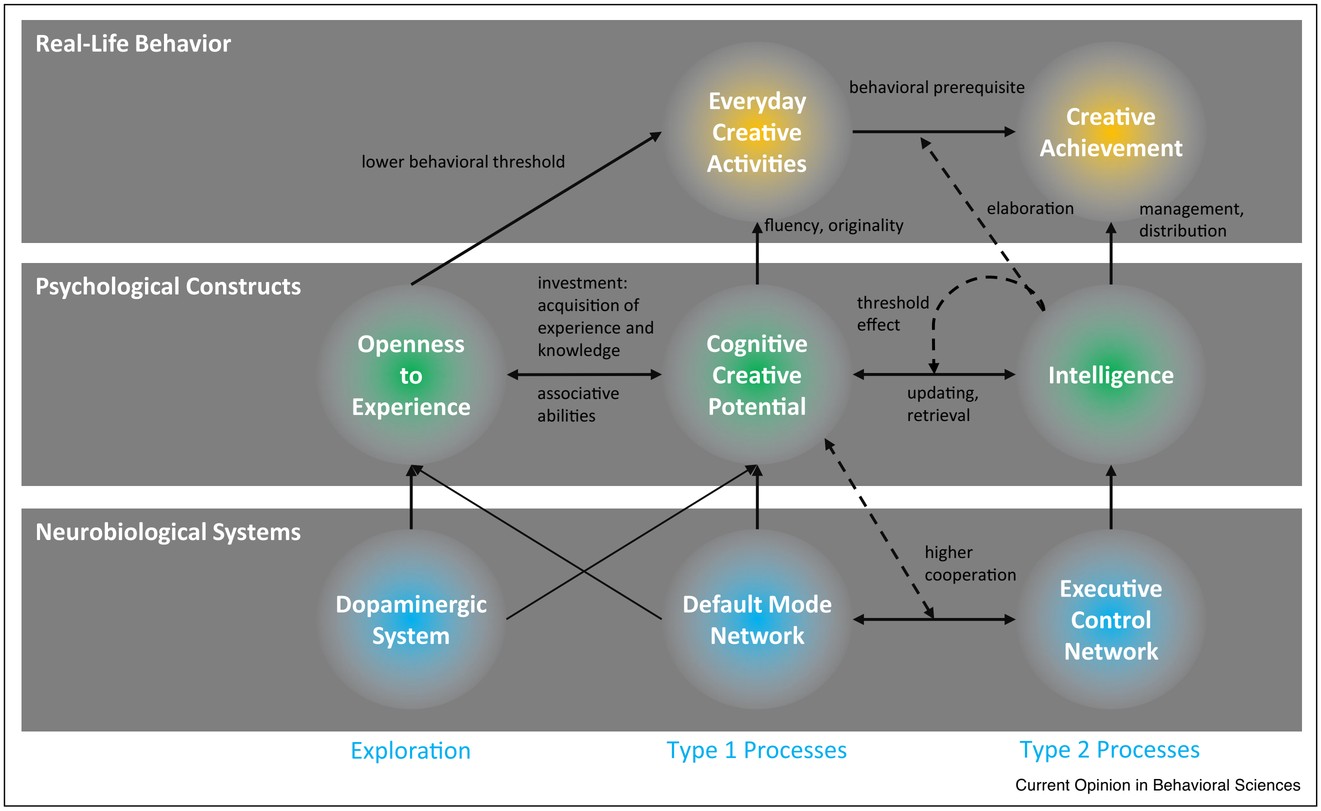
The overall aim of the model is to provide a framework for understanding interindividual differences in real-life creative behavior (top level). To this end, everyday creative activities are distinguished from socially acknowledged creative achievement [2••]. In light of the many domains of creative endeavor [3], the model adopts a *domain-general* view, which means that domain-specific factors are not highlighted. In the following, I will present evidence from studies that address individual differences on at least one of the levels included in the model. I will start with the middle level of psychological constructs, turn the discussion of their respective neurobiological systems, and finally to an integrative discussion of real-life creative behavior.

Psychological constructs

Personality constructs: openness to experience

At the level of psychological constructs, personality and ability predictors of creative behavior can generally be distinguished. Arguably, the one personality trait that is most consistently associated with different indicators of creativity is openness to experience [4, for second order meta-analysis, see 5]. Open people characterize themselves as curious and imaginative, which intuitively appears as a good basis for creativity. But which are the mechanisms by which openness fosters creativity? There are at least two possible pathways: First, openness is thought to *lower the behavioral threshold* for the engagement in creative everyday activities [6]. This effect is proposed to relate to exploration behavior driven by dopaminergic activity (see below). Second, openness fosters the acquisition of experience and knowledge (crystallized intelligence) over time [7]. This makes openness an *investment trait* for creativity [8]. Open people not only possess a rich basis of knowledge, but also have a more interconnected semantic memory structure [9], on the basis of which cognitive creative potential (in terms of divergent thinking ability; see below) can operate to produce novel ideas [10,11]. These two pathways may explain the effect of openness on the exertion of creative

Figure 1



Bio-psycho-behavioral model of creativity. Solid lines indicate causal and correlational effects; dashed lines indicate moderator effects.

activities and the association between openness and cognitive creative potential.

Current models of openness differentiate two or three aspects between the overall openness factor and its facets [12•,13]. The openness aspect (cognitive engagement with perception, fantasy, aesthetics, and emotion) is more closely related to creative accomplishments in the arts, whereas the intellect aspect (cognitive engagement with abstract and semantic information) is more related to creativity in the sciences [14•]. The third recently proposed aspect, open-mindedness (nontraditionalism, variety-seeking, diversity [12•]) has not yet been studied in relation to creativity in its present form. It might be hypothesized that this aspect is a domain-general promoter of creativity, as it was for instance found that multicultural experiences enhance creative cognition [15]. Within the model proposed here, open-mindedness might be most closely associated with lowering the behavioral threshold for creative activities.

Ability constructs: cognitive creative potential and intelligence

At the heart of individual differences in creativity stands cognitive creative potential in terms of divergent thinking ability, the ability to produce novel and useful ideas [16]. Cognitive creative potential predicts real-life creative activity, and indirectly (via creative activity) also creative achievement [1]. Among cognitive creative potential, qualitative (ideational originality) and quantitative (ideational fluency) indicators of cognitive creative potential can be discerned. Ideational originality is closely tied to intelligence (with latent correlations around 0.5; for an overview see [17]), while fluency is not [18]. The shared variance among intelligence and ideational originality is substantially due to executive functioning, particularly updating ability [19]. Also, retrieval ability is related to both, ideational originality and intelligence, which supports the executive account of cognitive creative potential [20].

Though general intelligence is highly related to qualitative indicators of cognitive creative potential, there is robust evidence showing that the relationship is nonlinear in the way that a certain level of intelligence forms a necessary but not sufficient condition for ideational originality (known as the *threshold hypothesis* [21,22,23•]). This means that as soon as an above-average IQ threshold is reached, cognitive creative potential is no longer dependent upon intelligence. An intriguing question for future research might be whether the threshold effect can be explained by working memory function or other executive functions.

Neurobiological systems

Three major brain systems are proposed to underlie the discussed psychological constructs: the dopaminergic system, the default mode network, and the executive control network (see Figure 1). While neither of these relationships is exclusive, and several links and overlaps exist, these systems are assumed to underlie the most distinctive characteristics of the respective psychological constructs.

Dopaminergic system

Dopamine is associated with approach-oriented behavior, novelty seeking, and exploration [24]. It was linked to openness on a genetic basis [25] and was labeled 'the neuromodulator of exploration', a central characteristic of openness [26]. Though dopamine is also related to extraversion [27], in the context of creativity, variation in dopaminergic activity may be best understood in terms of individual differences in the rewarding potential of uncertainty [26]. Consistent with the notion of the relevance of dopaminergic brain systems for openness, connectivity between the mesocortical network was found to relate to openness to experience, which is thought to foster orienting towards salient stimuli and make open people 'permeable' for incoming information [28].

Higher levels of dopamine are accompanied by decreased latent inhibition [29], which is also related to openness [30], and creative achievement [31]. Latent inhibition is thought to link creativity to subclinical expressions of psychopathology such as schizotypy [32], though clinical manifestations of schizophrenia are clearly negatively associated (for a recent meta-analysis see [33]). Cognitive ability is being perceived as a moderating factor between mental illness and creative expression [34]. Interestingly, 'leaky' attention is positively associated with creative achievement, while it is negatively associated with cognitive creative potential [35]. This points to different paths to creative achievement: while leaky attention might be beneficial when longer time periods are considered, it might be detrimental to creativity in shorter time, such as divergent thinking, which requires focused attention and executive control [36]. In line with this, different dopaminergic genetic profiles were associated with cognitive creative potential and creative achievement [37].

Dopamine has further been associated with creativity in clinical observations of patients treated with dopamine agonists [38], which are confirmed by experimental evidence showing that dopaminergic medication fosters divergent thinking ability [39]. Associations between dopamine and cognitive creative potential were reported on a genetic basis [40]. Brain structural studies found gray matter volume in striatal regions to be associated with variation in cognitive creative potential [41,42]. Integrity of white matter tracts between striatal and frontal regions was also related to cognitive creative potential [43]. Just recently, a functional imaging study using an ultra-high-field scanner revealed activity in subcortical dopaminergic regions during the subjective experience of insight, which is assumed to be intrinsically rewarding [44••]. A recent model of dopaminergic systems in creativity differentiates the effects of striatal and prefrontal dopamine on creativity [45•]. It is argued that medium levels of both striatal and frontal dopamine levels lead to flexibility (striatal) and persistence (frontal).

Default mode and executive control networks

The brain bases of interindividual differences in cognitive creative potential and intelligence are currently seen in the default and executive control networks (cf. [46]). Again, it needs to be emphasized that these relationships are by no means isomorphic, the psychological constructs are overlapping, and the respective networks cooperate during creative cognition (see below). Nonetheless, the functions of these networks display striking similarities to processes expressed in dual-process models of human cognition. Type 1 processes, which are hypothesized to emerge from default mode activity, are conceptualized as automatic, rapid, effortless, and associative. Type 2 processes, hypothesized to emerge from executive control activity, are described as controlled, slow, effortful, and analytic [47].

The default mode network is active in the absence of goal-directed thought (i.e. during resting state [48]) and during cognitive processes that involve self-generated or spontaneous thought [49,50]. Numerous functional imaging studies report involvement of default mode regions in creative cognition (for meta-analyses see [51,52]). On an interindividual differences level, highly creative individuals show higher gray matter volume in default mode structures such as the precuneus [41,42,53,54], increased coupling between default mode and executive regions during rest [55], and, as recently observed across several independent datasets, increased coupling during creative idea production [56••].

The executive control network is currently viewed as the brain network corresponding most closely to intelligence-related processes. Interestingly, the brain regions identified as core nodes of the executive control network in recent years align well with brain areas postulated by the parieto-frontal integration theory, the long-time standard model of the neural bases of intelligence [57,58]. This is substantiated by the robust association between working memory function, a core module of intelligence, and activation of the dorsolateral prefrontal cortex [59]. A recent meta-analysis on the parieto-frontal integration theory also highlights the role of the dorsal attention network [60].

Taken together, neuroscience studies point to the involvement of both, default mode and executive networks in creative cognition, which is in accordance with behavioral research and the long-lasting notion of interplay between type 1 and type 2 processes in creative cognition. Individual differences in structure and function of the respective brain areas are related to individual differences in cognitive creative potential and intelligence, respectively. Cooperation between default and executive networks is needed for creative idea generation, and the degree of cooperation relates to interindividual differences in cognitive creative potential [56••,61].

Real-life creative behavior: an integrative perspective

At the level of real-life creative behavior, everyday creative activities and creative achievement can be distinguished. While the former refer to personal creative behavior in terms of everyday creativity or little-C, creative achievement is conceptualized in terms of socially recognized accomplishments or pro-C/big-C [62]. Creative activities are normally distributed, with most people showing some extent of creative activity, whereas creative achievement follows a skewed distribution, meaning that only few individuals attain high levels [1,2••].

In a previous study [1], we sought to disentangle the effects of openness, cognitive creative potential, and intelligence on real-life creative behavior. The obtained results are schematically depicted in Figure 1. Openness and cognitive creative potential were related to the exertion of creative activities, but not directly related to creative achievement. As argued above, it is proposed that dopamine-driven approach-orientation associated with openness lowers the behavioral threshold for engagement in creative activities. In addition, openness fosters the acquisition of a rich basis of experience and knowledge. This may lead to a more interconnected memory structure, which can be accessed in divergent thinking processes to produce original ideas. For this, it is assumed that the interplay between type 1 (default mode) and type 2 (executive control) cognitive processes is particularly fruitful. The relative dominance of type 1 and type 2 processes likely depends on the time perspective and situational demands (short/focused versus long/defocused [36]).

For predicting creative achievement, finally, three effects turned out to be relevant in our previous study: (1) the direct effect of the amount of engagement in creative activities, (2) the interactive effect of creative activities and intelligence, and (3) the direct effect of intelligence. (1) The direct effect of creative activity on creative achievement describes a higher likelihood for people who engage in creative activities to also display creative achievement. It can be considered a *behavioral prerequisite*. This effect likely corresponds to expertise in more big-C-oriented models of creativity [63]. (2) The interactive effect of creative activity and intelligence describes the *elaboration* of creative ideas or products, which depends conjointly on experience and cognitive ability. This effect is most likely to account for the transition from a normal to a skewed distribution, as it depends on the simultaneous presence of a rare combination of openness, cognitive creative potential, and intelligence. (3) The additional direct effect of intelligence, finally, describes the effect that is presumably least specific (though important) to creativity and related to the *management* of complex tasks and also the *distribution* of creative ideas or products. The notion that this effect is not specific to creativity is substantiated by the common observation that these tasks are often carried out by others than the creative individuals themselves.

Limitations and conclusion

The model presented here is intended as a domain-general account to the prediction of real-life creative behavior. As such, it does not encompass constructs that are relevant to domain-specific creativity, such as conscientiousness in the sciences, or neuroticism in the arts [4]. Also, the model does not encompass the vital aspect of motivation. Though motivation, particularly intrinsic motivation, has long been recognized as a driving force of creative endeavor [64], it is not confined to creativity. Intrinsic motivation can fuel any kind of human passion, including those that are not commonly considered creative.

Finally, it shall be acknowledged that the model presented here is at some points simplistic, as it cannot speak to all the diverse cross-associations between the discussed constructs. For instance, openness was also associated with default mode network efficiency [65], as was dopamine associated with cognitive creative potential (see above). It is reasonable to assume that the two neurobiological systems and the respective psychological constructs — which are closely related — influence each other. It might also be the case that there is a common biological basis, or multiple bases, to both constructs. To systematically disentangle the effects, more research spanning multiple layers of analysis with multiple neurobiological systems and psychological constructs is needed. While, admittedly, this goal sounds ambitious, it might still be the only way to gather a complete and dependable understanding of the multifaceted phenomenon of human creativity. Studies that do not consider a complete set of theoretically relevant variables run at the risk of L.O.V.E.[1] Therefore, conceptual frameworks, such as the one presented here, might help to guide future research.

[1] Left Out Variables Error: Biased estimates due to important covariates being left out in a multivariate model.

Conflict of interest statement

Nothing declared.

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