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Creative Expertise Is Associated With Transcending the Here and Now

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Human imagination is bounded. As situations become more distant in time, place, perspective, and likelihood, they also become more difficult to simulate. What underlies the ability to successfully engage in distal simulations? Here we examine the psychological and neural mechanisms underlying distal simulation by studying individuals known for transcending these limits: creative experts. First, 2 behavioral studies establish that creative experts indeed succeed at engaging in vivid distal simulations, compared to less creative individuals. Performance on a traditional measure of creativity (Study 1) and real-world success in creative pursuits (Study 2) corresponded with more vivid distal simulations across temporal, spatial, social, and hypothetical domains. Study 3 used neuroimaging to identify the neural mechanism supporting creative experts' simulation success. Whereas creative experts and controls recruit the same neural mechanism (the medial prefrontal cortex) while simulating common or proximal events, creative experts preferentially engage a distinct neural mechanism (the dorsomedial subsystem of the default network) while simulating distal events. Moreover, creative experts showed greater functional connectivity within this network at rest, suggesting they may be prepared to engage this mechanism, by default. Studying creative expertise provides new insight into the ability to mentally transcend the here and now.

Keywords: simulation, psychological distance, creativity, imagination

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Through mental simulation, we can project ourselves into alternate times, spaces, perspectives, and hypothetical situations (Liberman & Trope, 2008; Buckner & Carroll, 2007). Simulation enables us to plan our futures and empathize with others (Schacter, Addis, & Buckner, 2008; Gaesser & Schacter, 2014; Gerlach, Spreng, Madore, & Schacter, 2014). Yet, simulation skills are bounded: We can only project ourselves a limited distance from reality. Although *proximal simulations*, such as considering what tomorrow may bring or what a friend may be thinking, are conjured with ease, *distal simulations*, such as considering what life will be like next century or what our enemies are thinking, are far more difficult (Baumeister, Vohs, & Oettingen, 2016; Liberman et al., 2008; Phillips & Cushman, 2017; Tamir & Mitchell, 2011; Trope & Liberman, 2003). These limits to distal simulation can produce erroneous inferences and biases, such as mispredicting our future feelings (Wilson & Gilbert, 2005), misunderstanding another person's beliefs (Nickerson, 1999), or undervaluing future rewards compared to present ones (Ersner-Hershfield, Wimmer, & Knutson, 2009; Hershfield & Bartels, 2018). What psychological and neural mechanisms might support successful simulation of distal experiences?

To understand distal simulation, here we adopt an approach known to provide insight into mechanisms supporting psychological processes: studying individuals with demonstrated expertise. Whereas clinical studies provide insight by studying individuals known for deficits in a cognitive process, here we seek insight by

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studying individuals with a particular aptitude. For example, researchers interested in the mechanisms supporting spatial navigation have studied professional taxi cab drivers in London (Maguire et al., 2000); researchers interested in perception-action coupling have studied professional dancers (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Cross, Hamilton, & Grafton, 2006). Here, we studied creative experts to gain insight into the processes supporting vivid distal simulation.

We turn to creative experts for two reasons. First, creative expertise has a face valid connection to vivid distal simulations: Novelists, actors, directors, and artists all transcend direct perception to create vivid stories, characters, and images. Second, creativity has been linked empirically to outcomes related to distal simulation, such as imagining the past and future (Förster, Friedman, & Liberman, 2004; Madore, Rose, & Schacter, 2015), spending time in a geographically distant location (Maddux, Adam, & Galinsky, 2010), and counterfactual thinking (Markman, Lindberg, Kray, & Galinsky, 2007). However, the link between creativity and distal simulation vividness has yet to be tested directly. Thus, our first goal (Studies 1 and 2) was to establish whether creative expertise is associated with more vivid distal simulations.

To the extent that creative expertise is indeed related to distal simulation, we can then leverage this population to gain insight into this process. In doing so, we can better understand how these capacities for creativity and vivid distal simulation relate to each other. To that end, the second goal was to determine the mechanism that may support vivid distal simulation. Here we arbitrate between two possibilities. One possibility is that creative experts recruit the same mechanism during distal simulation that supports proximal simulations, but to a greater extent than control (i.e., less creative) participants. In this scenario, although control participants may only engage their simulation muscle to imagine proximal events, the creative expert may continue to engage this same muscle to simulate more distal realities. That is, creative individuals engage the same underlying mechanism during simulation, even as events gets more challenging to imagine. An alternative possibility, however, is that creative experts recruit a distinct mechanism during distal simulations from the one that supports proximal simulations. If so, creative experts and controls would engage the same simulation muscle to imagine proximal experiences, but only creative experts would engage a different muscle to simulate distal experiences. That is, proximal and distal simulation may rely on at least partially unique underlying mechanisms, and creative experts can tap into the separate mechanisms as events get more challenging to imagine.

Our final study (Study 3) used functional MRI (fMRI) methods to arbitrate between these two possibilities. Past research has identified the brain's default network as critical to multiple types of simulation (Buckner et al., 2007; Buckner, Andrews-Hanna, & Schacter, 2008). The default network comprises (a) a core system (anterior medial prefrontal cortex; posterior cingulate), (b) a dorsomedial subsystem (dorsomedial prefrontal cortex, temporoparietal junction, and temporal poles extending into inferior frontal gyrus), and (c) a medial temporal lobe subsystem (posterior inferior parietal lobule, retrosplenial cortex, parahippocampal cortex, hippocampal formation; Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010; Yeo et al., 2011). In the general population, the default network's core system is more active during proximal, relative to distal, simulation (Tamir & Mitchell, 2011), reflecting limits to distal simulation. This core default system is implicated in self-reflection (Kelley et al., 2002) and thus it is thought to support imagining the self's immediate experience across proximal temporal, spatial, social, and hypothetical domains. If creative experts use the same mechanism to simulate proximal and distal experiences, then they should engage the core default system similarly during proximal and distal simulation. If so, activity in the core default system during distal simulation should differentiate creatives from controls and may indicate that successful distal simulation is associated with stretching the self to farther times, places, perspectives, and hypotheticals.

Alternatively, if creative experts use a unique mechanism during distal simulations, then they should show the same proximal simulation pattern found in the general population (greater core system activity for proximal, relative to distal, simulations) but also increase activity in other regions of the brain—perhaps a distinct default network subsystem—for distal, relative to proximal, simulations. The dorsomedial subsystem is consistently associated with imagining alternative points of view (Frith & Frith, 2006; Saxe & Kanwisher, 2003; Denny, Kober, Wager, & Ochsner, 2012), whereas the medial temporal subsystem is associated with episodic simulation, or imagining details from the past and future (Addis & Schacter, 2008; Schacter et al., 2008). Both of these processes require suspending proximal experience. Thus, if creative experts preferentially engage either of these systems during distal simulation, then successful distal simulation may require transcending the proximal self to imagine alternative temporal, spatial, social, and hypothetical realities. Moreover, if creative experts rely more heavily on one of these subsystems, then it would further suggest that the corresponding psychological process (i.e., perspective taking vs. episodic simulation) may be particularly useful for generating vivid distal simulations.

The present research leverages creative expertise as a means to understand the cognitive and neural mechanisms supporting successful distal simulation. First, we measured creative expertise in the general population and assessed whether this expertise is associated with vivid simulation (Study 1). We then specifically recruited professional experts in creative fields (and comparable control participants) to assess simulation vividness (Study 2) as well as brain activation during proximal and distal simulation (Study 3). We combined self-report, linguistic, and brain imaging methods as multiple convergent measures of distal simulation. This multimethod, multisample approach provides novel insight into how humans imagine distant times, spaces, perspectives, and hypothetical situations.

Study 1

Methods

In each study, participants provided informed consent in accordance with the Princeton University Institutional Review Board. All measures and exclusions are reported. In each study, we collected additional measures of social skills (e.g., the Empathy Interpersonal Reactivity Index [Davis, 1983] and the Autism Quotient Scale [Allison, Auyeung, & Baron-Cohen, 2012] for exploratory analyses). Because they are outside the scope of this report, results from these measures are not reported here. All materials and data are made available on Open Science Framework (https://osf.io/cy8wt/).

Participants. We recruited participants ($N = 301$; M age $= 37.16$, $SD = 11.35$; 121 males) from Amazon Mechanical Turk (MTurk). MTurk reduces the sampling bias widespread in psychology by recruiting individuals beyond the typical Western, educated, industrialized, rich, and democratic participants (i.e., university undergraduates; Henrich, Heine, & Norenzayan, 2010; Berinsky, Huber, & Lenz, 2012; Buhrmester, Kwang, & Gosling, 2011; Paolacci, Chandler, & Ipeirotis, 2010). We targeted a sample of 300 participants to provide sufficient statistical power to detect small to moderate correlations between simulation skills and creativity.

Procedure. Participants completed (a) a distal simulation task, (b) a control simulation task, (c) a measure of creativity, and (d) the Short Form of the Raven Advanced Progressive Matrices (Arthur, Tubre, Paul, & Sanchez-Ku, 1999), a standard measure of IQ (IQ; task order counterbalanced).

Distal simulation task. For the distal simulation task, participants were shown a simulation prompt in the temporal (e.g., imagine what the world will be like in 500 years), spatial (e.g., imagine being on the bottom of the ocean), social (e.g., imagine being an angry dictator), and hypothetical (e.g., imagine the continents never divided) domains. Participants were shown the prompt for 2 min and were instructed to imagine the experience and write a description of their simulation.

To derive a subjective measure of distal simulation, participants next rated the quality of their simulations in response to four questions: (a) How vividly did you imagine the experience? (b) To what extent did you see what you imagined in your mind's eye? (c) To what extent did you feel immersed in what you imagined? and (d) How difficult was it for you to imagine the experience (reverse scored). Participants responded using a 1 (*not at all*) to 100 (*extremely*) sliding scale. Responses were averaged across simulation prompts to create a composite self-reported simulation quality score.

In addition, to derive an objective measure of distal simulation skills, participants' written responses to the simulation prompts were submitted to a lexical analysis that specifically targets simulation quality (Bucci & Maskit, 2006). This lexical analysis measures the weighted number of function words (i.e., pronouns, articles, propositions, and conjunctions) that are critical to formulating ideas and communicating to a listener/audience (Murphy, Maskit, & Bucci, 2015; Pennebaker, 2011). Each function word is assigned a weight (between 0 and 1) that reflects the extent to which inclusion of that function word in narrative descriptions correlates with more vivid descriptions (rated by independent judges). Past work has shown that this measure correlates with episodic detail and narrative vividness (Nelson, Moskovitz, & Steiner, 2008). Lexical analysis scores were averaged across simulation prompts to create a composite, objective measure of simulation quality. Subjective and objective simulation scores were significantly correlated, $r(299) = .206$, $p < .0001$, suggesting they tap into a similar, though nonredundant, construct of simulation vividness.

In addition to the simulation prompts, participants also completed a prompt with a similar format, but that did not induce any simulation. During this control task, participants were shown a visual illusion and were provided 2 min to describe the image. Participants also rated the extent to which they felt immersed in and focused on the task and their written responses were submitted to the same lexical analysis as the simulation prompts. This control task allowed us to examine the extent to which creativity is associated with distal simulation vividness, rather than task engagement and writing skills more generally.

Creativity task. We measured creativity using divergent thinking prompts (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005; Torrance, 1980), for which participants were asked to generate (a) as many uses as possible for a pen and (b) as many ways as possible to improve a megaphone, respectively (order counterbalanced across participants). Participants were provided 5 min per creativity prompt and responses were scored by SparCit's creativity assessment based on their fluency, elaboration, flexibility, and originality (Beketayev & Runco, 2016). Consistent with past work (Torrance, 1980; Runco & Albert, 1985), *fluency* was defined as the number of unique ideas generated by the participant and *elaboration* was defined as the amount of detail provided in generated ideas. Flexibility and originality were scored with semantic networks. To determine flexibility, for each generated item, the semantic categories associated with that item were computed based on pre-existing semantic networks found in Word Association Network (https://wordassociations.net/en/dictionary) and WordNet (Fellbaum, 1998). Next, the semantic similarity between every two answers was computed, with less similarity indicating greater flexibility. Originality was defined as the uniqueness of ideas, based on how far apart the ideas are in semantic networks, adjusted by the idea association frequency rate generated by ideas presented in Wikipedia in 2014. Importantly, past research using these measures of flexibility and elaboration has found that they strongly correlate with nonautomated scoring procedures for assessing these constructs (Beketayev & Runco, 2016). Each participant's fluency, elaboration, flexibility, and originality scores were normalized to be on the same scale and averaged to create a composite creativity score. Because creativity scores to each divergent thinking prompt were significantly correlated, $r(299) = .55$, $p < .0001$, we averaged these scores to derive a composite creativity measure (see Supplementary Tables S1–S3 in the online supplemental material).

Analyses. To test whether individual differences in creativity were associated with the vividness of distal simulations, we conducted two linear regression models to examine whether (a) objective and (b) subjective distal simulation outcomes predict creativity scores. Next, we included performance on the control condition (attending to and describing a visual illusion) as a covariate in regression models to examine the extent to which observed relationships were specific to distal simulation, rather than task demands independent of simulation more generally. Regression was also used to examine whether IQ was related to creativity and/or distal simulation vividness.

Results

Both objective and subjective simulation vividness were positively associated with creativity—$\beta_{\text{objective}} = .14$, $t(299) = 2.48$, $p = .014$, $R^2 = .02$; $\beta_{\text{subjective}} = .20$, $t(299) = 3.53$, $p < .0001$, $R^2 = .04$ (Supplementary Table S4 in the online supplemental material). These results not only indicate that greater creativity is associated with more vivid distal simulations, but also that the relationship is not tautological. That is, creative thinking is related to, though not fully redundant with, distal simulation skills.

Just as participants provided subjective ratings of their simulations, they provided subjective ratings of their control task performance (i.e., to what extent were you focused on the image in front of you? To what extent did you feel immersed in the image in front of you?). Creativity was also significantly associated with subjective performance on the control task—$\beta_{\text{subjective}} = .25$, $t(299) = 4.38$, $p < .001$, $R^2 = .06$. Critically, the relationship between subjective simulation vividness and creativity remained significant when controlling for subjective performance on the visual control task ($\beta_{\text{objective}} = .14$, $t(299) = 2.41$, $p = .016$, $R^2 = .21$). Moreover, creativity was not associated with objective vividness in participants' written responses during the control task—$\beta_{objective} = .09$, $t(299) = 1.53$, $p = .13$, $R^2 = .008$. Notably, IQ was related to creativity, $\beta = .244$, $t(299) = 4.34$, $p < .0001$, $R^2 = .06$. However, IQ was unrelated to objective distal simulation vividness—$\beta = .037$, $t(299) = .65$, $p = .517$, $R^2 = .001$—and negatively related to subjective simulation vividness ($\beta = -.129$, $t(299) = 2.25$, $p = .025$, $R^2 = .02$), consistent with prior work on the dissociation between IQ and simulation (Lind, Bowler, & Raber, 2014). Thus, the shared variance between creativity and IQ is unrelated to the shared variance between creativity and distal simulation.

Study 2

Study 1 demonstrates a positive association between distal simulation vividness and performance on a divergent thinking task among participants in an online marketplace. The goal of Study 2 was to conceptually replicate and extend Study 1 with a more externally valid operationalization of creativity. In this study, we specifically recruited people who qualified as creative experts. We compare creative professionals to professionals in noncreative industries, to test whether real-world creativity is associated with success in vivid distal simulations.

Methods

Participants. Research has identified professionals in the arts and entertainment as the most creative among a wide range of professions, as operationalized using standard measures of creativity, such as divergent thinking tasks (Beketayev, Eskafi, Mukhamejanov, & Beketayev, 2016). In Study 2, we therefore recruited creative experts from the arts and entertainment. In addition, we recruited a control group, targeting professionals working in the legal, medical, and financial industries, based on research that identified individuals in these professions as scoring in the mid-to-low range on standardized tests of creativity (Beketayev et al., 2016). Sample size was determined based on effects observed in Study 1. That is, we compared the objective distal simulation scores from participants with the top 25th percentile of creativity scores to those from the bottom 50th percentile and used the corresponding effect size to determine the number of creative experts and controls to recruit in Study 2. This analysis suggested that 78 participants per condition would provide 80% power. To ensure we collected at least 78 participants per condition, we aimed to recruit 100 per condition. Ultimately, 100 creative experts and 97 controls completed Study 2, which corresponds with 88% power.

We defined *expert* as any individual who either had been recognized by a prestigious award for their creative work (e.g., a Guggenheim award in the visual arts, a New York City Film Festival award, a Sundance Screenwriting Award, or a Macarthur Fellowship), held a position at a prestigious institution known for excellence in the domain (e.g., a novelist with a position in Princeton University's creative writing program, or a performer with the Upright Citizen's Brigade), and/or attained commercial success in their domain (e.g., wrote a bestselling novel or hit TV show). We targeted writers, actors, directors, and visual artists because we wanted a range of creative expertise, while still ensuring that our creative experts had experience imagining distant times, places, perspectives, and counterfactuals. For this reason, we did not recruit musicians or dancers, as their creative process requires simulation content (e.g., sound and movement) known to engage brain systems unrelated to imagining other times, places, perspectives, and counterfactuals (e.g., the auditory and sensorimotor systems; Calvo-Merino et al., 2005; Cross et al., 2006; Kraus & Chandrasekaran, 2010; Luo et al., 2012). The final sample included 100 creative experts (42 writers, 31 actors/directors [actors and directors are combined into one category, as these participants had significant expertise in both domains], and 27 visual artists). We recruited 97 control participants (35 in the legal, 29 in the medical, and 33 in the financial industries) who were also highly successful, but in these less creative domains. We targeted specific professional groups (e.g., Princeton area law firms, hospitals, online forums for these kinds of professionals, etc.) and then tried to match them to the creatives we had in terms of gender and age and career success. Specifically, recruitment was tiered; first, we recruited creative experts and looked for control professionals who were qualified and interested. We then scheduled a creative first and then turned to our database of interested, potential control subjects. We could then select a control subject from this set of interested participants who was matched on as many demographic dimensions as possible to the scheduled creative expert.

We confirmed that this sample of real-world creative experts was indeed more creative than the control sample by replicating past work examining creativity between these professions (Beketayev et al., 2016): creative experts significantly out-performed control participants on the creativity tests used in Study 1 ($M_{\text{creatives}} = 606.76$, $SD = 80.60$; $M_{\text{controls}} = 583.50$, $SD = 60.04$; $t(190) = 2.27$, $p = .024$, Cohen's $d = .33$). Correlations between creativity performance and distal simulation vividness are reported in Supplementary Table S5 in the online supplemental material.

Despite their difference in creativity, creative expert and control groups were matched on gender, $\chi^2(1) = 0.13$, $p = .715$, $w = 0.03$, as well as income and education level, $t\text{s}(189) < 1.07$, $p\text{s} > .281$, Cohen's $d\text{s} < .17$. Creative professionals were older than control participants—$M_{\text{creatives age}} = 46.88$ years, $SD = 14.19$ years; $M_{\text{controls age}} = 35.35$ years, $SD = 11.83$ years, $t(179) = 5.94$, $p < .001$, Cohen's $d = .88$; thus group comparisons included analyses controlling for age differences between groups (see Results).

Critically, participants also rated how successful they have been in their career with a 0–100 scale, and our creative and noncreative professionals showed similar levels of high success in their professions—$M_{\text{creatives}} = 70.14$, $SD = 18.19$; $M_{\text{controls}} = 68.40$, $SD = 19.55$; $t(181) = 0.62$, $p = .54$, Cohen's $d = .09$ (Figure 1)—allowing us to test the relation between distal simulation vividness

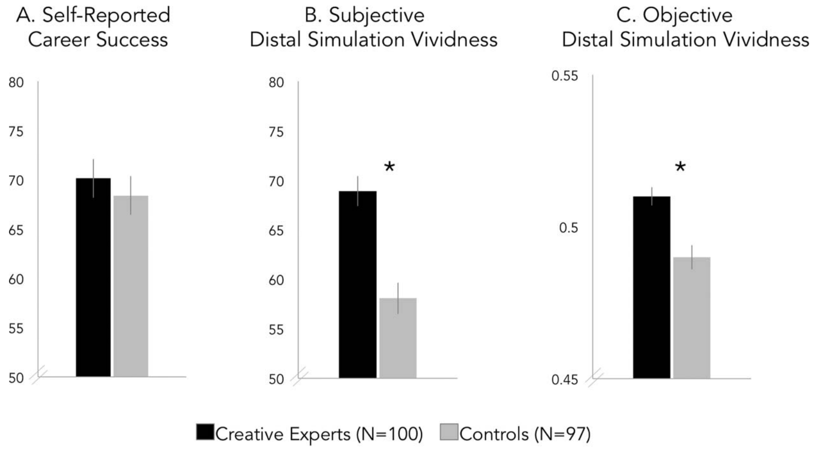

Figure 1. Results from Study 2. (A) Creative experts and controls are matched on self-reported career success. Relative to controls, creative experts demonstrate greater (B) subjective distal simulation vividness and (C) objective distal simulation vividness. Asterisks (*) indicate statistical significance ($p < .05$). Full scales ranged from 0 to 100 although are truncated on the y-axes for display.

and creative expertise, rather than expertise more generally. Note that participants who chose not to report their gender (N creatives = 6), education level (N creatives = 6), career success (N creatives = 6), and/or age (N creative experts = 12, N controls = 4) were excluded from group difference analyses on those respective characteristics.

Procedure. Both samples completed the online distal simulation task used in Study 1, in which they were shown simulation prompts in the temporal (e.g., imagine what the world will be like in 500 years), spatial (e.g., imagine being on the bottom of the ocean), social (e.g., imagine being an angry dictator), and hypothetical (e.g., imagine the continents never divided) domains, as well as a control prompt (visual illusion). Participants were shown prompts for 2 min. For the simulation prompts, participants were instructed to imagine the experience and write a description of their simulation; subsequently, they rated the quality of their simulation. For the control prompt, participants were instructed to attend to the image and describe what they saw; subsequently, they rated the extent to which they were immersed in and focused on the task.

Analyses. Two general linear models were used to test whether, relative to controls, creative experts produced more vivid (a) objective and (b) subjective distal simulations. Next, performance on the control condition (visual illusion) was added as a covariate in these models to test the extent to which observed patterns were specific to distal simulation, rather than task performance more generally. Because creative experts were on average older than controls (see Participant section above), we also tested whether group differences in objective and subjective distal simulation remained significant when adding age as a covariate in the models.

Results

In line with our hypotheses, creative experts produced more vivid distal simulations than controls—$F_{\text{subjective}}(1, 195) = 24.37$, $p < .0001$, $\eta_p^2 = .11$; $F_{\text{objective}}(1, 195) = 6.10$, $p = .014$; $\eta_p^2 = .03$ (Figure 1). As in Study 1, creativity was also associated with greater subjective immersion and focus on the control task, $F_{\text{control task subjective}}(1, 195) = 11.76$, $p = .001$, $\eta_p^2 = .06$; however, the difference between creative experts' and controls' subjective distal simulation vividness remained significant when controlling for participants' subjective ratings on the control task, $F_{\text{subjective}}(1, 194) = 19.16$, $p < .0001$, $\eta_p^2 = .09$. As in Study 1, objective simulation vividness on the control task was unrelated to creativity, $F_{\text{objective}}(1, 195) = 3.76$, $p = .54$, $\eta_p^2 = .002$. Age was unrelated to simulation vividness ($r_{subjective} = .07$, $p = .346$; $r_{objective} = .023$, $p = .754$) and greater objective and subjective distal simulation vividness for creative experts (vs. controls) remained significant when controlling for age, $F(1, 178)$'s > 6.91, p's $< .01$, η_p^2s $> .03$.

Study 3

Studies 1 and 2 examine whether creativity is associated with more vivid distal simulation. Results from these two studies converge: Creativity is associated with vividly simulating distant times, spaces, perspectives, and hypothetical realities. Thus, we can next ask: How do creative experts succeed in vividly simulating distal events? Here we arbitrate between two possibilities: (a) creative experts recruit the same mechanisms during proximal and distal simulation, but to a greater extent than controls during distal stimulations, or (b) creative experts recruit a distinct mechanism to mentally simulate more distant times, spaces, perspectives, and hypothetical realities. In Study 3, we turned to functional MRI (fMRI) methods to determine which of these possibilities best explains how creative experts vividly simulate distal events. Past work has found that portions of the default network's core system (e.g., medial prefrontal cortex) engages more strongly during proximal, relative to distal, simulation (Tamir et al., 2011). If creative experts use the same mechanism to simulate proximal and distal experiences, then they should engage the core default system similarly during proximal and distal simulation. If so, activity in the core default system during distal simulation should differentiate creatives from controls. In contrast, if creative experts use a distinct mechanism during distal simulations, then they should show increased activity in other regions of the brain—perhaps a distinct default network subsystem—for distal, relative to proximal, simulations.

Methods

Participants. Sample size was determined based on objective simulation vividness effects observed in Study 2. This analysis suggested that 29 participants per condition would provide 80% power and thus we aimed for 30 participants per condition. Ultimately, given logistical constraints, we were only able to recruit 27 creative experts (13 writers and 14 directors/actors; 15 males, 12 females) and 26 controls (10 financial, 10 medical, and 6 legal professions; 15 males, 11 females) to participate in Study 3, which corresponds with 79% power. Exploratory analyses on the data from Study 2 revealed that writers and directors/actors demonstrated the greatest distal simulation skills (Supplementary Figure S1 in the online supplemental material). A contrast comparing writers and directors/actors to all other professions revealed that writers and directors/actors demonstrated superior simulation skills relative to visual artists and legal, medical, and financial professionals—$F_{\text{subjective}}(1, 196) = 28.81$, $p < .0001$, $\eta_p^2 = .15$; $F_{\text{objective}}(1, 196) = 8.97$, $p = .003$, $\eta_p^2 = .04$. Given that Study 3's goal was to determine the mechanism that supports more vivid distal simulation, we specifically recruited professional writers, directors, and actors as our creative experts, to ensure our sample could elicit the most vivid distal simulations. Otherwise, the same qualifications employed in Study 2 were used in Study 3 for both the creative and control sample, with the additional requirement that participants were safe for MRI scanning (e.g., no indication of metal in their body).

Prior to their lab session, participants completed the same online measure of creativity used in Studies 1 and 2. As in Study 2, and consistent with past work examining creativity between these professions (Beketayev et al., 2016), creative experts significantly out-performed control participants on this standard creativity test ($M_{\text{creatives}} = 636.83$, $SD = 86.60$; $M_{\text{controls}} = 577.46$, $SD = 81.82$), $t(40) = 2.28$, $p = .028$, Cohen's $d = .65$, further suggesting that this sample of real-world creative experts are indeed more creative than the control sample. Groups did not vary in age, $M_{\text{creatives}} = 36.08$ years, $SD = 9.85$ years; $M_{\text{controls}} = 33.73$ years, 7.32 years, $t(50) = 0.98$, $p = .33$, Cohen's $d = .27$; education level, $t(45) = 0.04$, $p = .97$, Cohen's $d = .02$; gender, $\chi^2(1) = 0.03$, $p = .88$, w = 0.001; or self-reported career success, $t(45) = 1.65$, $p = .11$, Cohen's $d = .48$. The groups differed in annual income, with controls earning more than creative experts, $t(51) = 4.19$, $p = .0005$, Cohen's $d = 1.15$. Nonetheless, the behavioral results reported did not interact with income, $F(1, 51) = 2.54$, $p = .12$, $\eta_p^2 = .04$, and the observed clusters of neural activity remain significant when controlling for income. The resting state connectivity results do not remain significant when controlling for differences in income ($p = .682$, $\eta_p^2 = .004$); however, income is nonsignificantly associated with dorsomedial subsystem resting state connectivity, $r(51) = -.21$, $p = .154$, and is therefore unlikely to be driving these results.

fMRI Task. Participants underwent fMRI while they simulated both proximal and distal experiences and rated the vividness of what they imagined. On each trial, participants were presented with either a proximal cue (e.g., self, in the next 24 hr) or distal cue (e.g., Obama, 100 years from now) as well as a simulation prompt (e.g., browsing a book store; Figure 2) and were instructed to simulate that event at the specified distance. Cues noted proximity across spatial, temporal, social, or hypothetical dimensions. Each trial comprised of a 14-s simulation period, followed by participants rating the vividness of their simulation on a 4-point scale anchored at 1 (not at all vivid) and 4 (extremely vivid) (up to 3 s). Directly after participants made their vividness rating, the screen advanced to an active baseline (detecting the presence of a visual illusion), which was jittered in timing. Jitter time was centered around 3 s and determined based on easy-optimize-x (Spunt, 2016). Simulation trials were presented in a random order across runs. Participants completed 120 trials, 30 in each of the social, temporal, spatial, and hypothetical domains (15 proximal and 15 distal). The simulation task comprised five runs of scanning, each 8 min, 29 seconds.

To help ensure that only the distal aspects of a simulation prompt (i.e., New York vs. Tokyo), rather than the corresponding events (i.e., browsing a bookstore), influenced a trial's distance, independent raters ($N = 43$) judged 40 events per domain in terms of their temporal, spatial, and hypothetical closeness. Events were also rated in terms of how social they are. The interrater reliability of these judgments was very high (Cronbach's alpha = .99),

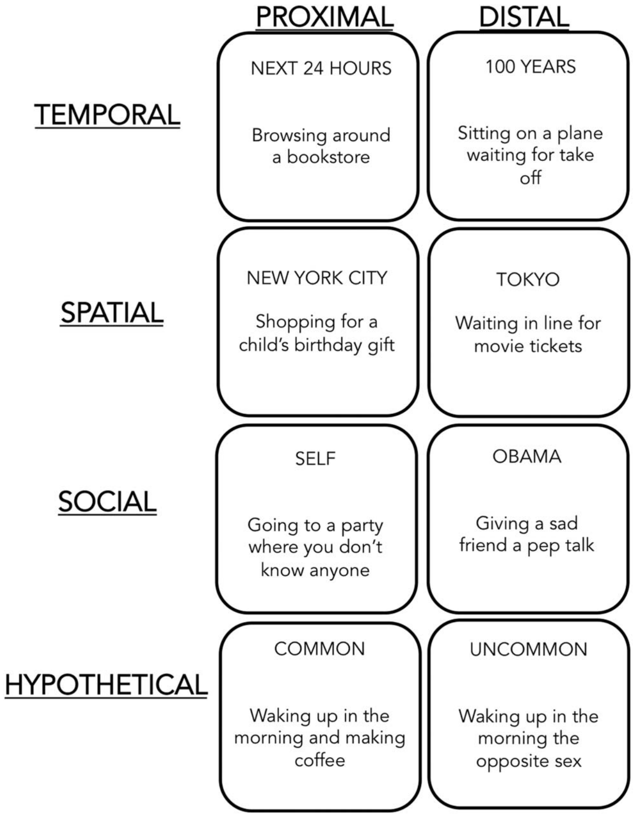

Figure 2. Functional MRI (fMRI) task. Participants completed 120 trials, 30 in each of the social, temporal, spatial, and hypothetical domains (15 distal and 15 proximal per domain).

indicating consensus in the extent to which stimuli met these criteria. Events that were rated closest and least social were selected for the temporal, spatial, and hypothetical trials, while scenarios that were rated closest and most social were selected for the social trials. Thus, all fMRI trials were considered close, allowing the distal cue to manipulate distance, and social trials induced the most social–cognitive processing.

Resting state scan. Participants also completed a 6-min resting state scan (i.e., while participants were merely lying still in the scanner) prior to the simulation task. This scan offers a measure of intrinsic functional connectivity in the default network. Default network regions show spontaneous fluctuations during rest that are reliably correlated (Greicius, Krasnow, Reiss, & Menon, 2003; Fox et al., 2005; Vincent et al., 2007). Thus, if creative experts show differences in default network regions during distal simulation, these may be mirrored by functional differences in the default network in the absence of a specific task.

MRI procedure. MRI scanning was conducted at the Princeton Neuroscience Institute with a 3 Tesla (T) Siemens Prisma scanner and 64-channel head coil. Functional scans were acquired with a $T2^*$-weighted echo-planar plus sequence with 69 interleaved slices (TR/TE = 1500/27ms, flip angle = 75°, 96 × 48 matrix, 2 mm thick, field of view [FOV] = 192; multiband acceleration factor = 3). Scanning began with a 6-min resting state scan. Next, participants completed the simulation task fMRI runs, followed by a Magnetization Prepared Rapid Gradient Echo scan (MP-RAGE; TR/TE = 2300/2.27, flip angle = 8°, 256 × 256 matrix, 1 mm thick, FOV = 250). Collection of the MP-RAGE allowed for fMRI data registration.

FMRI analyses. Functional images were preprocessed using SPM12 (Wellcome Department of Neurology). Preprocessing steps included spatial realignment with rigid body transformation, unwarping, normalization, and smoothing (6 mm Gaussian kernel, full width at half maximum). For the simulation task analyses, each participant's preprocessed data was modeled in the general linear model framework. We modeled regressors for each simulation type (i.e., temporal, spatial, social, hypothetical) separately for each distance (i.e., distal, proximal), as well as six motion regressors for each of the motion parameters from image realignment. Simulation trials were modeled as a boxcar from the onset of the trial until the offset of the participant's vividness rating (high-pass filter = 128 s). For each subject, we computed the distal > proximal and proximal > distal contrasts across all simulation types (i.e., temporal, spatial, social, hypothetical), as well as separately for each simulation type for follow-up analyses. Group comparisons were made by directly comparing subject-level contrasts for the creative experts versus controls. Brain activity from the group comparisons were considered significant if they passed the threshold $p < .001$, and corresponding family wise-error (FWE) determined cluster size. Results were subsequently thresholded at $p < .0001$ with FWE cluster correction to reveal which clusters survive even more conservative thresholding.

For resting state analyses, data were preprocessed in SPM12, with the same steps used in the task analyses (6 mm Gaussian kernel, full width at half maximum). Following past work (Fox et al., 2005; Tambini, Ketz, & Davachi, 2010; Vincent et al., 2007), the resting state data were high-pass filtered at 111 s to remove low frequencies below .009 Hz. Preprocessed resting state data were then submitted to a general linear model in which we modeled nine nuisance regressors and their temporal derivatives for the six motion parameters, mean activation in white matter and ventricles, and the global mean and saved the residual images from this output.

We then assessed—in the residual images for which nuisance regressors were partialed out—functional connectivity (i.e., time-course correlations) in three default network systems, as identified through clustering analyses of resting state data by Yeo and colleagues (2011). These subsystems correspond to the core system, dorsomedial subsystem, and medial temporal subsystem. We extracted the clusters larger than 20 voxels for each system from the 17 network cortical parcellation available through freesurfer (freesurfer.net/fswiki/CorticalParcellation_Yeo2011).

For each of the three default network subsystems, we calculated the average time course in each region. We then calculated pairwise correlations between each region in the network and used Fisher's z' transformation to normalize the correlation coefficients in R statistical software (Version 1.7.5). The z-statistics of all pairwise correlations within the network were averaged to produce the functional connectivity within each network. Each pairwise Fisher's z score within a network was averaged to create each network's mean connectivity. These mean connectivity scores were then compared between creative experts and controls. The same approach was used in exploratory analyses of cross-network connectivity (see Supplementary Table S7 in the online supplemental material). Three creative experts and one control participant did not complete their resting state scan, leaving a final sample of 24 creative experts and 25 controls for the resting state analyses.

Finally, we used the same approach described above to test for functional connectivity differences in the default network during the simulation task (i.e., task-based functional connectivity). The same steps applied to resting state scans were applied to the simulation task to compare functional connectivity in creative experts versus controls for distal and proximal simulation conditions, respectively.

Results

Replicating Studies 1 and 2, creative experts rated their distal simulations as significantly more vivid than controls, $t(51) = 2.99$, $p = .002$, Cohen's $d = .83$. In contrast, the two groups showed equivalent levels of vividness for proximal simulations, $t(51) = .09$, $p = .465$, Cohen's $d = .02$; Figure 3. This pattern reflected a significant Group (creative vs. control) × Distance (proximal vs. distal) interaction, $F(1, 51) = 17.84$, $p < .0001$, $\eta_p^2 = .26$ (see Supplementary Table S6 in the online supplemental material for post hoc simple effect comparisons). Such findings suggest that creativity may be specifically associated with an advantage in distal simulation skills, rather than simulation skills more generally.

The neuroimaging results support the hypothesis that creative experts exhibit superior distal simulation because they recruit a unique mechanism when simulating distant realities. Whole-brain analyses revealed that creative experts and controls both showed greater activity in regions of the core system of the default network—including anterior medial prefrontal cortex and posterior cingulate/precuneus—for proximal, relative to distal, simulations (Figure 4A; Supplementary Tables S8 and S9 in the

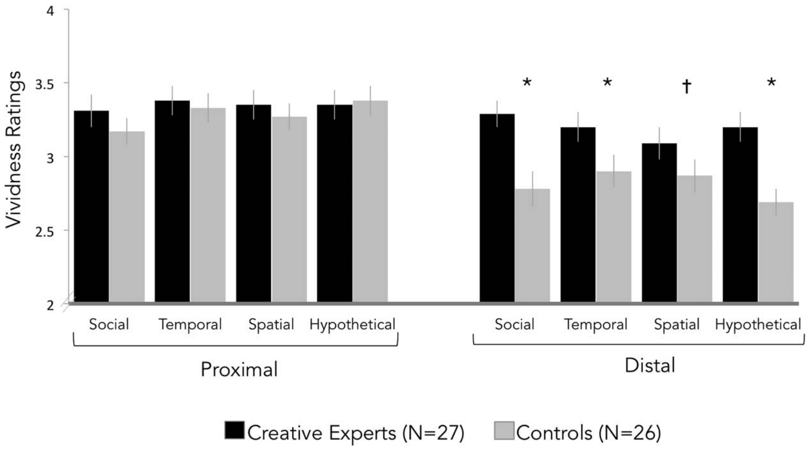

Figure 3. Behavioral results from Study 3. Creative experts report more vivid distal simulations than controls in all four domains. Both groups reported equivalently vivid proximal simulations. Asterisks (*) indicate statistical significance at $p < .05$ and the dagger (†) indicates marginal significance ($p = .08$).

online supplemental material). This finding is consistent with prior research in the general population on proximal simulation (Tamir et al., 2011). However, only creative experts showed greater activity in regions of the dorsomedial subsystem—including dorsomedial prefrontal cortex (dMPFC), right temporoparietal junction (rTPJ), and inferior frontal gyrus (IFG) extending into temporal pole (TP)—for distal, relative to proximal, simulations. The whole-brain interaction confirmed that creative experts preferentially engage the dorsomedial subsystem (DMPFC, rTPJ, and IFG extending into TP) for distal, relative to proximal, simulation

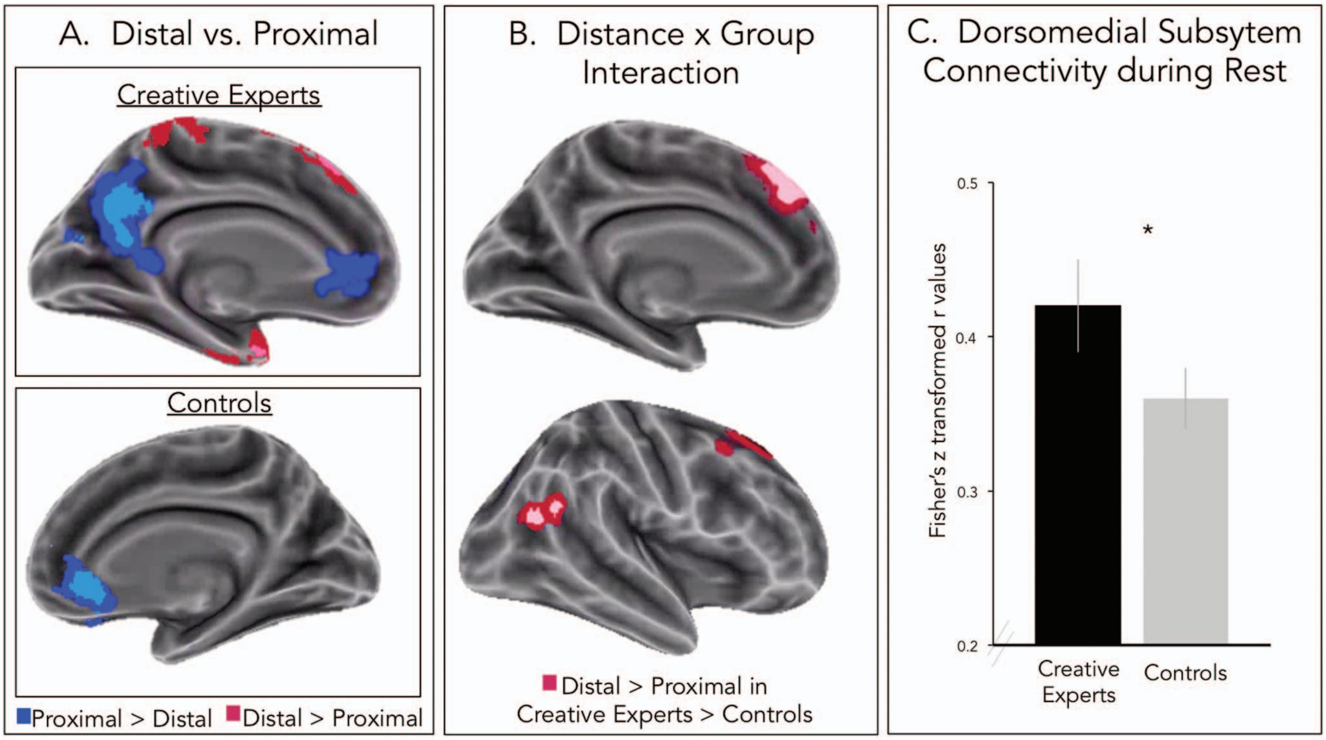

Figure 4. Neuroimaging results from Study 3. A: Brain regions showing greater activation for distal (vs. proximal; pink) and proximal (vs. distal; blue) simulation, shown separately for creative experts and controls. B: Compared to controls, creative experts show greater dorsomedial subsystem activation for distal (vs. proximal) simulations. Results family wise-error (FWE)cluster corrected at $p < .0001$ (lighter clusters) and $p < .001$ (darker clusters). C: Creative experts (vs. controls) show greater dorsomedial subsystem functional connectivity during rest.

(Figure 4B). Follow-up exploratory analyses demonstrated that creative experts show increased dorsomedial subsystem activity in response to distal simulation for all four of the simulation domains (i.e., social, temporal, spatial, and hypothetical; Supplementary Figure S2 in the online supplemental material), suggesting the dorsomedial subsystem facilitates distal simulation similarly across each domain.

Next, we followed up on these activation results to see if the dorsomedial subsystem not only showed greater activation during distal simulation in creative experts, but also whether this system showed greater functional connectivity during distal simulation in creative experts. Consistent with our activation results, creative experts demonstrated greater functional connectivity than controls in the dorsomedial subsystem during distal simulation ($M_{\text{creatives}} = .63$, $SD = .13$, $M_{\text{controls}} = .55$, $SD = .13$), $t(51) = 2.22$, $p = .03$, Cohen's $d = .62$, but not proximal trials ($M_{\text{creatives}} = .62$, $SD = .13$, $M_{\text{controls}} = .57$, $SD = .13$), $t(51) = 1.51$, $p = .14$, Cohen's $d = .39$. Functional connectivity between regions of the medial temporal lobe subsystem did not differ between groups for either the proximal ($M_{\text{creatives}} = .68$, $SD = .15$, $M_{\text{controls}} = .67$, $SD = .13$), $t = .39$, $p = .70$, Cohen's $d = .06$, or distal trials ($M_{\text{creatives}} = .65$, $SD = .17$, $M_{\text{controls}} = .63$, $SD = .15$), $t = .46$, $p = .65$, Cohen's $d = .12$. Interestingly, the core system showed greater functional connectivity for creatives versus controls for both the proximal ($M_{\text{creatives}} = .71$, $SD = .13$, $M_{\text{controls}} = .63$, $SD = .08$), $t = 2.68$, $p = .01$, Cohen's $d = .74$, and distal trials ($M_{\text{creatives}} = .68$, $SD = .12$, $M_{\text{controls}} = .61$, $SD = .11$), $t = 2.32$, $p = .03$, Cohen's $d = .61$, suggesting that this system may show greater task-based communication in creatives during all types of simulation.

Finally, if the dorsomedial system indeed facilitates distal simulation, then its recruitment during distal trials should also relate to participants' self-reported distal simulation vividness. Multiple results are in line with this suggestion. First, distal simulation vividness was significantly correlated with activation in the DMPFC, $r(51) = .29$, $p = .04$, and TPJ, $r(51) = .34$, $p = .01$, clusters observed in our whole-brain analyses during distal (vs. proximal) trials. Next, we performed the same analyses with independently defined DMPFC and TPJ regions of interest (ROIs; Yeo et al., 2011). We again observed that distal simulation vividness significantly correlated with DMPFC activity, $r(51) = .28$, $p = .02$, and marginally correlated with the TPJ activity, $r(51) = .23$, $p = .05$, during distal (vs. proximal) simulation. Finally, distal simulation vividness was significantly correlated with functional connectivity within the dorsomedial subsystem during distal (vs. proximal) trials, $r(51) = .26$, $p = .02$. Visualization of these results can be seen in Supplementary Figure S3 in the online supplemental material. Collectively, these results further suggest that the ability to engage the dorsomedial subsystem during distal simulation may be directly related to the ability to generate vivid simulations.

Creative experts likewise demonstrated significantly greater resting state functional connectivity than controls in the dorsomedial subsystem ($M_{\text{creatives}} = .43$, $SD_{\text{creatives}} = .13$; $M_{\text{controls}} = .36$, $SD_{\text{controls}} = .10$), $t(47) = 2.02$, $p = .026$, Cohen's $d = .60$ (Figure 4C). Differences in resting-state connectivity were specific to the dorsomedial subsystem—core system: $M_{\text{creatives}} = .50$, $SD_{\text{creatives}} = .15$, $M_{\text{controls}} = .47$, $SD_{\text{controls}} = .12$, $t(47) = 0.97$, $p = .21$, Cohen's $d = .22$; MTL subsystem: $M_{\text{creatives}} = .40$, $SD_{\text{creatives}} = .13$, $M_{\text{controls}} = .40$, $SD_{\text{controls}} = .14$, $t(47) = 0.08$, $p = .42$, Cohen's $d < .0001$—suggesting creative expertise may be associated with baseline differences in this subsystem. That is, the components of the dorsomedial subsystem may be more in sync with one another, by default, in creative experts compared to controls. It is also worth noting that across subjects, functional connectivity was greater within each default network system than between, for both creative experts and controls (ps $< .01$). This observation is consistent with prior research (Andrews-Hanna et al., 2010; Yeo et al., 2011) and further suggests that our results are specific to an organized dorsomedial subnetwork of the default system.

Together, the fMRI results suggest that while the core subsystem of the default network may facilitate the proximal simulations that most individuals conjure with ease, the dorsomedial subsystem of the default network supports the more challenging distal simulations available to creative experts.

General Discussion

Creative expertise offers a window into distal simulation. Three studies established a robust relationship between distal simulation and creativity. Performance on a traditional measure of creativity (Study 1) and real-world success in creative pursuits (Studies 2 and 3) corresponded with greater subjective (self-report) and objective (text analysis) measures of distal simulation vividness. We next used neuroimaging (Study 3) to identify how experts succeed at vividly simulating distant realities. Results support the claim that distal simulation requires a mechanism distinct from that recruited during proximal simulation. Creative experts and controls both preferentially engaged the core default network to simulate proximal events. However, only creative experts preferentially engaged the default network's dorsomedial subsystem, both in terms of mean level activity and functional connectivity, to simulate distal events. The distal simulation skills associated with creativity may therefore rely on distinct mechanisms from those supporting our everyday, proximal imaginings. During a rest period that occurred prior to completing the simulation task, creative experts also showed greater dorsomedial subsystem connectivity, suggesting creative individuals may be neurally prepared to transcend the here and now and/or engage in vivid distal simulation by default.

The dorsomedial subsystem showed increased activation during distal simulations in creative experts during each of the tested domains (temporal, spatial, social, hypothetical). Such findings are consistent with research supporting construal level theory (Bar-Anan, Liberman, Trope, & Algom, 2007; Wakslak & Trope, 2009; Liberman & Trope, 2014), which suggests that an abstract processing style (e.g., focusing on higher level causes, goals, or values relative to low-level details) underpins distal simulation across time, space, social perspective, and hypotheticality (Liberman et al., 2008; Liberman et al., 2014). Although the dorsomedial subsystem is consistently associated with considering other people's intentions and personality traits (Frith et al., 2006; Saxe et al., 2003; Denny et al., 2012), it is also implicated in seemingly disparate processes, including narrative comprehension (Simony et al., 2016), representing distances across domains (Parkinson, Liu, & Wheatley, 2014), semantic thinking (Binder, Desai, Graves, & Conant, 2009; Fairhall & Caramazza, 2013; Baetens, Ma, Seen, & Van Overwalle, 2014), and forming high-level construals (Baetens et al., 2014; Spunt & Adolphs, 2015; Spunt, Kemmener, & Adolphs, 2016; Gilead, Liberman, & Maril, 2014). These processes may be linked by their higher level of abstraction. Indeed, abstraction may be the thread that ties creativity to distal simulation skills, as construing events and objects abstractly also momentarily increases creativity (Ward, Patterson, & Sifonis, 2004).

Importantly, creative experts did show increased activity in the hippocampus during distal versus proximal simulation (see Supplementary Table S8 in the online supplemental material), pointing to the possibility that episodic simulation also supports distal imagination. However, this cluster of activation did not survive the whole-brain interaction comparing the distal (vs. proximal) simulation of creative experts to controls, and follow-up ROI analyses further confirmed that the hippocampus did not differentiate creative experts from controls on our task (see Supplementary Table S9 in the online supplemental material). One possibility is that processes underpinned by the dorsomedial subsystem may be more important than those supported by the medial temporal lobe system for distal simulation. An alternative possibility is that there are multiple routes to distal simulation, with creative experts preferentially using the dorsomedial system for distal simulation success whereas other populations that may excel in distal simulation may recruit the medial temporal lobe system. Future research can help tease apart these competing possibilities.

Our findings complement and extend new discoveries on the neural basis of creativity. Recent findings suggest that the default network works in conjunction with brain regions associated with executive function (e.g., dorsolateral prefrontal cortex) and attention (e.g., cingulate cortex) to support divergent thinking, the creative process of generating and exploring possible solutions to a problem (Beaty, Benedek, Silvia, & Schacter, 2016; Beaty et al., 2018). Yet, the precise roles played by each of these systems during divergent thinking are not known. Divergent thinking tasks tap into multiple mental processes, which may include not only simulation, but also idea maintenance in working memory, as well as idea evaluation and elaboration. In our brain imaging study, we only observed the default network—specifically the dorsomedial subsystem of the default network—as critical to distal simulations, pointing to the possibility that this network may support a similar process during divergent thinking. Future studies should disentangle the multiple processes involved in divergent thinking. For example, whereas the default network may contribute to the simulation of ideas, the executive and salience networks may support the maintenance, selection, and elaboration of ideas during creative problem solving.

These findings also offer interesting implications for combatting failures of distal simulation including empathy gaps whereby people struggle to adopt the perspective of those dissimilar (i.e., socially distant) from them (Nickerson, 1999). Our results suggest that creativity—which we found was associated with superior distal simulation—may also be associated with reduced empathy gaps. Previous research has indeed demonstrated a relationship between creativity and perspective taking: perspective taking increases creativity, a phenomenon that is mediated by distal simulation (Polman & Emich, 2011). In children, divergent thinking skills develop in tandem with theory of mind (Suddendorf & Fletcher-Flinn, 1999) and some theoretical accounts suggest that pretend play in childhood, which requires simulating myriad social perspectives, functions to promote creativity in adulthood (Russ, 2014). Indeed, our findings dovetail with research showing that human virtues such as wisdom likewise include the suspension of personal experience and the consideration of multiple points of view (Grossman et al., 2010; Kross & Grossman, 2012). Nonetheless, research on creativity tends to emphasize its importance for fostering innovation and career success (e.g., Simonton, 1997). Our results suggest a novel positive benefit of creativity—it may help us better connect with others. Future research may reveal whether and how creative pursuits help close empathy gaps.

It is worth noting that in Study 2, writers, directors, and actors (but not visual artists) showed advantages in distal simulation. We therefore recruited this subset of creative experts in Study 3 so that we were best positioned to isolate the brain mechanisms associated with vivid distal simulations. These creative experts have expertise in generating and communicating fiction, in particular, potentially limiting the generalizability of our neural findings to other forms of creative expertise. That said, this does not compromise our findings that vivid distal simulations engage the dorsomedial subsystem, which was the purpose of Study 3. Future research may help disentangle whether distal simulation skills are preferentially enhanced by creative expertise with fiction.

Taken together, results from this multimethod, multisample approach revealed that people can vividly simulate distal experiences. Specifically, creative experts experience and demonstrate an exceptional ability to imagine distal events. Creative experts accomplish these feats by switching on a distal simulation muscle that appears to be harder to engage for less creative individuals. Creativity may help us get outside ourselves, extending our imaginations to farther times, spaces, perspectives, and hypothetical realities.

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