A Systems Model of Ideation

By

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## Abstract

According to the systems model of creativity, it is at the intersections of individual, social, and cultural factors where creativity takes place. Given this model, postulating a social vacuum and focusing solely on individual creativity may be to significantly forego ecological validity. Insightful as the original systems model is, there has been no model that explains creative processes at the more concrete level of ideation (idea generation and evaluation) in terms of those three factors. Study I suggests that the traditional approach of individual-versus-group ideation has little merit, by adding to the growing body of evidence that, first, hybrid brainstorming is motivating and, second, that effective evaluation of creative ideas can in fact be done, particularly with certain adequate combinations of group and individual sessions. Study II further highlights the necessity to integrate the individual, social, and cultural levels, by first demonstrating that creative dynamics at only the individual level or the social (group) level can change dramatically when we consider them together, and secondly, revealing how a cognitive constraint in the form of a shared norm can indeed be liberating for creativity. Study III emphasizes the significance of cultural norms—that shape our mind at a fundamental level, though we may be unaware of their impact—for creativity, by discovering whether and under which conditions inductive, deductive, and abductive reasoning norms enhance creative cognition. Taken together, these studies both elaborate the original systems model with empirical data that center around specific ideation behaviors, as well as add to the model testable theoretical claims for future research. They result in a new, systems model of ideation, a derivative model of the basic systems approach to creativity. This dissertation comprises three studies that are independent from, yet build upon, each other in light of the systems approach.

Study I and Study II look at different parts of the data from one large experiment and make analyses that do not overlap. While the introduction and conclusion shed light on the conceptual connections among the three studies, Study I contributes most directly to the development of the systems model of ideation.

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# Introduction

Creativity does not take place in a social vacuum. The systems model of creativity by Csikszentmihalyi (1997, 1999) shifts researchers' chief focus away from the individual to a related system of three essential factors—cultural, social, and individual—that altogether inform creativity. At least two key assumptions here are that (1) the modern creative process requires an ongoing working group and socially invested research and development, which individuals alone cannot achieve, and (2) given our social contexts, an idea must be expressed, persuaded, and accepted by others in order to have any creative effect (Csikszentmihalyi, 1997; Sawyer, 2012). Isolated individuals' creativity is "necessary" (Csikszentmihalyi & Sawyer, 2014, p. 67), yet contributions of groups and individuals must be harmonized at the social (group) and cultural (organizational) levels: Groups share relevant information (e.g., creative needs, goals, constraints, and ideas) to motivate individuals to communicate novelty to the group in return, and selectively acknowledge individual creative contributions, while culture (or an organization) that seeks and rewards creativity under certain normative patterns of reasoning is a major driving force behind groups and individuals. In the systems model, first, not only individual but also socio-cultural factors and ramifications of creativity, such as the (organizational) culture of collective experimentation (Amabile et al., 2014; Edmondson, 1999), team building (Henningsen & Henningsen, 2013), recognition and networking (Dennis & Reinicke, 2004), satisfaction of process and outcome (Nijstad & Stroebe, 2006), and intrinsic and extrinsic motivation (Amabile & Pratt, 2016), can all be addressed. Secondly, the model elevates communication, an unsung discipline in creativity research, to a key source of insights.

Studies I, II, and III take the systems model as an overarching approach to creative ideation (i.e., generation and selection of creative ideas). They build upon prior research that used different foci and levels of analysis—individual-cognitive, social-affective, and cultural-normative. Together, they examine how individuals and groups provide cognitive and affective benefits that are complementary to each other within cultural (organizational) norms that encourage out-of-the-box thinking. In doing so, each study uniquely contributes to the creativity literature by addressing gaps at the intersections of individuals, groups, and organizations while taking the vantage point of communication.

Study I is published at the *Small Group Research*. The authors are Paul Hangsan Ahn, Lyn M. van Swol, Sang Jung Kim, and Hyelin Park. This study takes on the creativity research tradition that has mostly focused on the cognitive level and regarded ideation mostly as a means to generate many unconventional solutions (Paulus et al., 2019). Within the context of groups and organizations, ideation is not only cognitive and generative but also affective (Dennis & Reinicke, 2004) and evaluative (Harvey, 2014). Comparing the individual-then-group (communicating) sessions, which is the norm in organizations (Hargadon & Bechky, 2006; Osborn, 1953; Sutton & Hargadon, 1996), with all-individual (noncommunicating) sessions, Study I finds communicating participants individually select more useful ideas and are more motivated than noncommunicating participants. While there had been a demonstrated lack of individual and group ability to distinguish creative from uncreative ideas (Faure, 2003; Putman & Paulus, 2009; Rietzschel et al., 2006), Study I adds to the growing body of evidence (see Rietzschel et al., 2010, 2014; see also Girotra et al., 2010) that creative decision making is in fact possible. The study further provides the first quantitative evidence that the addition of group communication to individual creative problem solving can enhance decision making quality. The individual-then-group—"communicating," or "hybrid"—condition would let participants appraise potential solutions from cognitively and emotionally attached (as an individual) as well as detached viewpoints (as a group). The hybrid structure would also enable real-time verbal and nonverbal feedback on the opinions shared.

Study II is currently being revised and resubmitted to a journal. The authors are Paul Hangsan Ahn, Lyn M. van Swol, Runzhi Mary Lu, Sang Jung Kim, Hyelin Park, and Robert G. Moulder. This study raises questions about the suggestion from cognitive psychology since 1950s—that meetings should be lengthier in order to obtain more creative ideas (Baruah & Paulus, 2016; Beaty & Silvia, 2012; Christensen et al., 1957; Johns et al., 2001; Johnson & D'Lauro, 2018; Milgram & Rabkin, 1980; Parnes, 1961; Phillips & Torrance, 1977; Runco, 1986; Ward, 1969). The suggestion has been based on the "serial-order effect," one of the most robust psychological findings (Beaty & Silvia, 2012) that people start off thinking of and sharing typical combinations of ideas before they move onto more unusual ones. However, the research design of those studies did not take into account the fact that, in the real world, members of a group, team, or organization tend to open up their problems to their colleagues and seek ideas from them only after exhaustively thinking about solutions on their own first (Sutton & Hargadon, 1996). The study shows that under this more ecologically valid, individual-then-group design, there is actually a "reverse" serial-order effect: Solutions that are expressed earlier in the meeting are rated as more creative than solutions proposed later in the meeting. Social comparison theory applied to creativity research predicts that, because people often compete in groups, they will want to be the first to say the most brilliant ideas in comparison to their peers (Festinger, 1954; Paulus, 2000). The brief individual reflection time before the meeting might allow members to come to the meeting prepared with these ideas. This radically challenges the long-standing suggestions that meetings should be lengthier in order to obtain more creative ideas, and has practical implications, because time is a highly scarce organizational resource (Amabile & Pratt, 2016).

Study III (consisted of Studies III-1 and III-2) is being prepared to be submitted to a journal. The expected authors are Paul Hangsan Ahn, Xin Zhou, Sewon Oh, Lyn M. van Swol, Christopher N. Cascio, Sang Ah Lee, and Matthew Minich. This study explores the effects of major reasoning norms for creative idea generation using functional near-infrared spectroscopy (fNIRS). Those norms, based on which members of an organization are expected to communicate to problem-solve, are induction, deduction, and abduction. They are fundamental forces shaping how people think, and abduction has long been touted as the only norm that enhances creative idea generation (e.g., Habermas, 1978; Martin, 2009; Peirce, 1878; Sætre & Van de Ven, 2021; Weick, 2005). Therefore, which mode of reasoning is the communication norm is likely to have the most generalizable effect on creativity across different social contexts (Joullié, 2016). However, no studies have tested this claim in a controlled laboratory experiment. In Study III-1, the norms are strictly defined and performance pressure, reflecting the organizational reality, is placed on participants. The neural and behavioral results, taken together, support the superiority of abduction over induction and deduction, while showing that deduction is more conducive to creativity than induction. A subsequent question then arises, because analogical reasoning, interchangeably referred to as induction, has been found to enhance creativity (Benedek et al., 2014; Green, 2018; Holyoak & Morrison, 2012). To reconcile this contradiction between findings from Study III-1 and the literature, Study III-2 uses the same but loosely defined norms, so that induction can be conceptualized as analogical reasoning. (Induction and deduction in loose forms are referred to in rhetorical theory as example and enthymeme, respectively [McBurney, 1936]. However, Study III avoids introducing these terms for simplicity purposes.) Additionally, less performance pressure is present considering consistency with the literature. In Study III-2, the advantages of one reasoning norm over another for creative idea generation found in Study III-1 largely disappear. Study III is the first creativity study that treats reasoning types as an independent variable and pioneers the field of organizational communication neuroscience.

The three studies are introduced in the following. Then, a conclusion follows in which a systems model of ideation is proposed.

## Study I: Enhanced Motivation and Decision Making from Hybrid Creative Problem Solving

> Although Study I was published at the *Small Group Research* (Ahn et al., 2022; https://doi.org/10.1177/10464964211043565), the published version has errors due to my inattention in some statistical notations, introductory details, and in my description of one of the findings in the abstract. They were left uncorrected despite my attempts, because of certain miscommunications between the production team and us the authors/editors in early 2022. The version of Study I included in this dissertation is clear of those errors.


### Abstract

Hybrid brainstorming is ecologically more valid than all-interactive or all-noninteractive brainstorming, yet understudied. Although ideational benefits of hybrid groups have been found, studies have rarely focused on its affective/motivational contributions or ability to select ideas. In a randomized experiment, noninteractive-then-interactive (hybrid) groups perceived (1) higher goal clarity, engagement, and task attractiveness, and (2) chose more useful ideas than all-noninteractive groups with the instruction to be critical in idea selection. Additionally, (3) only participants in the hybrid condition individually selected ideas that were more useful, thus of overall higher quality, than the nonselected.

A series of lab experiments (Meadow & Parnes, 1959; Meadow et al., 1959; Parnes & Meadow, 1959) support that "a brainstorming session, when properly conducted, can produce more good ideas than a conventional conference" (Sutton & Hargadon, 1996, p. 686). However, due to production blocking, social loafing, and evaluation apprehension, brainstorming groups that interact tend to produce ideas of lower quantity and quality than individuals brainstorming separately (Stroebe et al., 2010). Without measures such as using a trained facilitator, electronic media, or groups with heterogeneous knowledge bases (DeRosa et al., 2007; Kramer et al., 2001; Stroebe & Diehl, 1994), creative performance of all-interactive groups would remain controversial.

## Generating Creative Solutions in a Hybrid

While noninteractive-versus-interactive brainstorming has long dominated the discussion on the utility of brainstorming (Korde & Paulus, 2017), available evidence refers us to the benefits of a *hybrid* of noninteractive and interactive brainstorming. First, brainstorming practitioners have consistently implied that for productive interactive brainstorming, time between each interaction should be packed with individuals' exhaustive efforts to generate ideas on their own (Brown, 2009; Kelley, 2001; Osborn, 1953). Korde and Paulus (2017), using face-to-face (FtF) brainwriting, accordingly found that hybrid sessions produce more ideas than those who repeatedly generate ideas either only noninteractively or only interactively (see also Ocker et al., 1998). More related to the present study, Rotter and Portugal (1969) used FtF brainstorming without a facilitator to compare across all-interactive, all-noninteractive, noninteractive-then-interactive (hybrid), and interactive-then-noninteractive (hybrid) groups. Both of their hybrid groups produced more ideas than all-interactive groups (see also Girotra et al., 2010) but fewer than all-noninteractive groups.

These findings suggest the potential as well as limitations of hybrid brainstorming, and encourage us to further investigate its productivity, given the paucity of data. Particularly, whether FtF hybrid brainstorming with a trained facilitator would perform better than all-noninteractive brainstorming without a facilitator remains untested. Since interactive brainstorming is typically led by a facilitator in managerial/organizational settings (Kelley, 2001; Osborn, 1953), including a facilitator in the study design may add ecological validity (Kramer et al., 2001; Offner et al., 1996)—though at the expense of some internal validity (see Limitations).

**Making Creative Decisions in a Hybrid**

Second, although many studies did not find evidence that either an all-noninteractive or all-interactive group can select better ideas than the other, nor that either group can discern the best ideas above chance level (Faure, 2004; Putman & Paulus, 2009; Rietzschel et al., 2006; though not without controversy, e.g., see discussion in Larey & Paulus, 1999), there are reasons for hybrid groups' potential to select better creative ideas. For example, pre-evaluation of ideas, which is highly compatible with or even spontaneous in a hybrid setting, has been found to later help select ideas with slightly higher overall quality (Rietzschel et al., 2010). Consistent with this pre-evaluation hypothesis, idea evaluation by noninteractive-interactive (hybrid) groups was positively, though very weakly, correlated to independent coders' evaluation, while there was no such correlation for all-interactive groups (Girotra et al., 2010). The necessity for selecting the best idea is assumed in brainstorming (Ahn & Van Swol, 2021). However, noninteractive-then-interactive groups' ability to select better ideas, particularly in comparison to all-noninteractive groups, has not been reported.

**Non-Idea Benefits**

Third, interactive brainstorming generates various non-idea benefits. Kramer et al. (1997) found that, compared to groups without training in brainstorming techniques, both all-interactive and all-noninteractive brainstorming groups perceived communication to be more satisfying, decision making more effective, and the group process more equitable. However, they did not find differences between all-interactive and all-noninteractive groups. Henningsen and Henningsen (2013) showed that all-interactive brainstorming groups experienced greater cohesiveness than all-noninteractive groups. This was consistent with a survey of managers and professionals by Dennis and Reinicke (2004), who showed that compared to either all-noninteractive or electronic brainstorming, all-interactive FtF brainstorming is perceived as more capable of supporting group well-being (group cohesiveness and relationships) and providing member support (individual growth and network building). Research on different types of hybrid brainstorming has also tested for non-idea benefits. Groups using a combination of FtF and asynchronous electronic brainstorming were more satisfied with their outcome ideas, though not process itself, than all-FtF groups or all-asynchronous electronic brainstorming groups (Ocker et al., 1998). De Vreede et al. (2010) found no differences in satisfaction with outcomes or process between multiple all-noninteractive groups versus multiple subgroups building on previous subgroups. However, we know of no research on non-idea benefits of noninteractive-then-interactive FtF hybrid brainstorming (see Hypotheses for reasons for this design).

The illusion of group productivity during interactive brainstorming is likely associated with various non-idea benefits like greater process satisfaction (Paulus et al., 1993, 1995). Nonetheless, as long as such non-idea benefits (1) are valuable in and of themselves in social/organizational settings (Dennis & Reinicke, 2004; Kramer et al., 1997), and (2) could feed into group performance in the long run (e.g., Rodríguez-Sánchez et al., 2017), this illusion of group productivity may not be problematic.

***Motivation from Interaction***

Sutton and Hargadon (1996) performed ethnographic research of highly innovative professionals at a leading design consulting firm. They reported that interaction, which is part of hybrid brainstorming, motivates each employee in that organization, imbuing them with lasting enthusiasm and vigor for their own projects after the meeting was finished (Sutton & Hargadon, 1996). To our knowledge, no quantitative study has focused on comparing motivation from all-noninteractive with hybrid brainstorming. Note as well that motivation is qualitatively different from some previously tested non-idea benefits (e.g., cohesiveness). While cohesiveness may not be a necessary component for creativity (the componential model of creativity; Amabile, 1988), motivation is—together with domain expertise and creative processes. Specifically, intrinsic motivation, which is described by a deep “commitment to” (task engagement) or being “attracted by” the work itself (Amabile, 1988, p. 133), is critical for creativity as opposed to extrinsic, controlling pressures or motivators such as expected evaluation, contracted-for rewards, or external directives. These extrinsic factors tend to fail to motivate (Amabile & Pratt, 2016). Notwithstanding their emphasis on intrinsic motivation, Amabile and Pratt (2016) recently updated their componential model by specifying that certain sources of influence external to an individual (e.g., funding for successful work or any social/organizational environment that helps focus on the given goal) may result in “synergistic extrinsic motivation.” As long as the extrinsic motivator does not attempt to control or override individuals’ self-autonomy, it can enhance intrinsic motivation. Given that any social environment that enables individuals’ deeper involvement with a task can be a synergistic extrinsic motivator (Amabile & Pillemer, 2012), we propose that hybrid brainstorming qualifies as one if it enhances perceived engagement and task attractiveness. Furthermore, clarity of an organizational or project "goal"—one of the foremost catalysts to create intrinsic motivation (Amabile & Pratt, 2016, p. 169)—is likely enhanced during interaction in hybrid brainstorming, because communication can foster a shared mental map (Weick, 1993).

## Hypotheses

The present study compares a hybrid of noninteractive-then-interactive brainstorming and all-noninteractive brainstorming using the FtF paradigm, for several reasons. First, both are arguably the most ecologically valid, and thus basic, two modes of brainstorming, at least in FtF settings (Sutton & Hargadon, 1996). Noninteractive brainstorming was considered the default and essential (Osborn, 1953). Interactive brainstorming was conceived as an adjunct to noninteractive brainstorming when individuals need help from others (Osborn, 1953; Paulus et al., 1995), so all-interactive brainstorming would be the least in sync with organizational practice. Interactive-then-noninteractive brainstorm, although useful, would be an exception when members lack basic knowledge of the topic (e.g., when kicking off a new project; Dugosh & Paulus, 2005; Sutton & Hargadon, 1996). Second, the noninteractive-then-interactive brainstorming sequence has been found to be more productive than the interactive-then-noninteractive sequence (Baruah & Paulus, 2008; cf. Paulus et al., 1995), and it has been widely known that all-noninteractive groups outperform all-interactive groups (Stroebe et al., 2010). Thus, it seems more interesting to compare the two (noninteractive-then-interactive groups and all-noninteractive groups) that have been found as more productive. Third, Study I builds partly on the FtF brainstorming study by Girotra et al. (2010), which compared noninteractive-then-interactive groups with all-interactive groups in idea generation and selection. For these reasons, we pit hybrid of noninteractive brainstorming followed by interactive brainstorming against all-noninteractive brainstorming.

**Goal Clarity**

Shared *vision*, or goal orientation, in a group promotes the collective pursuit of creative solutions (García-Morales et al., 2006). In a task environment, people rely on a mental model, an organized knowledge structure unique to each individual (Mathieu et al., 2000). For team functioning, ongoing communication is pivotal to translate individual mental models into a shared one (April, 1999) and encourage a superordinate goal (Weick, 1993). Thus, hybrid group members who communicate with each other can better reflect on the common goal to reach in comparison to all-noninteractive groups, who do not benefit from such interaction.

H1: Members of a hybrid group will perceive their goal with greater clarity in comparison to members of an all-noninteractive group.

**Perceived Engagement**

Maslach et al. (2001) define engagement[1] as marked by *vigor* and *absorption*. *Vigor* is a high level of energy and mental resilience. *Absorption* is being fully focused and engrossed in work and is likened to *flow* (Schaufeli et al., 2002), which involves centering of attention, loss of self-consciousness, and deep sense of enjoyment (Csikszentmihalyi, 1990). Engagement in creative collaboration generates intense momentum (Osborn, 1953) and instigates a back-and-forth dynamic of enthusiasm (Brown, 2009), which carries it through "the darkest and most pressure-tinged stages of a project" (Kelley, 2001, p. 56). Without it, a team would not be able to stay on course or reach solutions to tough problems (Kelley, 2001). These outcomes of brainstorming are likely to be unique to a hybrid group.

[1] Dedication, as a subcategory of engagement, was not tested in the present study.

H2-a: Hybrid group members will have greater *vigor* than all-noninteractive group members.

H2-b: Hybrid group members will experience deeper *absorption* in the task compared to all-noninteractive group members.

**Task Attractiveness**

A tendency to join, leave, or stay with a brainstorming group would be affected by how much a member perceives the task of brainstorming attractive to perform. This is distinct from the social attractiveness of a group, which exists when members are attracted to a group because of, for example, sharing similar values (Carron et al., 1985). Innovative processes are iterative and nonlinear (Brown, 2009), so an organization that wants to innovate ought to have its employees engage and re-engage in the ideation process often and consistently. Moreover, creative thinking is physically and mentally demanding (Csikszentmihalyi, 1988). If idea generation per se is unattractive and daunting as a task, without associated processual rewards, members would not desire to re-engage in the activity. Enjoyable idea generation would, by contrast, attract members to reengage. In an ethnographic study (Sutton & Hargadon, 1996), employees described group brainstorming as “most invigorating” (p. 700) and said that they “had to go” (p. 697) and brainstorm despite their busy schedule. A number of quantitative studies supported this conclusion (e.g., Paulus et al., 1993; Stroebe et al., 1992). We extend this result to hybrid brainstorming:

H3: Hybrid group members will be more attracted to the given creativity task compared to all-noninteractive group members.

**Generation of Ideas**

By stating that "the creative power of the individual still counts most," Osborn (1953, p. 139) clarified the relationship between interactive and noninteractive idea generation as complementary rather than competitive, though this idea has not been fully reflected in the literature (Korde & Paulus, 2017). Further, there are likely other reasons than ideas (e.g., goal clarity, engagement, and task attractiveness) for group brainstorming (Sutton & Hargadon, 1996). Thus, extending previous findings that all-noninteractive groups outperform all-interactive groups in idea quantity and quality in FtF settings (though in electronic brainstorming and brainwriting it has been shown that groups can be better than solitary brainstorming, DeRosa et al., 2007; Korde & Paulus, 2017) to the comparison between FtF all-noninteractive and hybrid groups would not lead us to simplistically conclude that hybrid groups are less useful than all-noninteractive groups. In line with H1 to H3, it would serve to examine if noninteractive and interactive brainstorming provide distinctly complementary benefits. A key assumption behind this interpretation would be that individuals are generally situated within social contexts where they alternate between interactive and noninteractive brainstorming to generate both motivation (Brown, 2009; Kelley, 2001) *and* creative ideas, particularly when one who has run out of new ideas wants to get unstuck (Sutton & Hargadon, 1996; see Dunbar, 1997). However, our design does not operationalize individual needs for a brainstorming meeting nor do our participants go through several alternating interactive and noninteractive sessions (see Korde & Paulus, 2017). Instead, we simply question if all-noninteractive brainstorming would outperform hybrid brainstorming, while being clear about what we cannot extrapolate from our results. Past research has largely supported the superior productivity of all-noninteractive brainstorming over all-interactive brainstorming (Stroebe et al., 2010). Additionally, the fact that all-noninteractive groups do not need time to share written ideas with others, whereas hybrid groups do at the start of and throughout the interactive session, increases the possibility that all-noninteractive groups will produce more ideas. However, it is possible hybrid brainstorming will outperform all-noninteractive brainstorming given the presence of facilitators during interaction, which tends to enhance productivity (Kramer et al., 2001; Offner et al., 1996; Oxley et al., 1996). Further, hybrid group members might generate a sufficiently large number of ideas in solitude during the first few minutes (when momentum is strong, Kohn & Smith, 2011), which precedes the interactive session. It is only with the nuanced understanding of the social contexts we have discussed that we ask:

RQ1: Will all-noninteractive groups outperform hybrid groups in quantity of ideas?

Studies revealed that idea quantity is positively associated with idea quality (Stroebe et al., 2010). Given the possibility that either all-interactive or all-noninteractive groups could outperform the other in idea quantity (RQ1) and that we determine idea quality by the number (instead of ratio) of ideas rated "good" on usefulness, originality, and both usefulness and originality (overall quality), we ask:

RQ2: Will all-noninteractive groups outperform hybrid groups in the number of non-selected ideas that are *good* on (a) usefulness, (b) originality, and (c) overall quality?

**Selection of Ideas**

Girotra et al. (2010) compared noninteractive-then-interactive (hybrid) brainstorming groups against all-interactive brainstorming groups. Their hybrid brainstorming groups first individually evaluated ideas at the end of the noninteractive phase and then interactively evaluated ideas after the interactive phase. This led the hybrid brainstorming groups to select ideas that were better than ideas selected by all-interactive groups, who evaluated ideas only once as a group after the interactive session. This finding is encouraging given the dearth of empirical research on idea selection (Paulus et al., 2019). There is also some realism in explicitly asking participants to evaluate their ideas before joining the group, because members of a group or organization would often be asked or expected to bring good ideas to the meeting. Yet, it is possible that (1) the explicit request for hybrid group members to rank ideas by the end of their first (noninteractive) phase, and (2) the difference in whether decision making was done alone or as a group may have affected results. Considering these points, in the present study, we test if hybrid groups will select better ideas than all-noninteractive groups when there is the same single request for both conditions to individually evaluate ideas at the end of the entire idea generation session.

Hybrid groups may excel in decision making for several reasons. One reason is that they are likely to voluntarily process their own ideas at least one more time than all-noninteractive groups. When the noninteractive phase ends and interaction starts, hybrid participants would likely share their high-quality ideas early. This would be due to them trying to appear competent to their peers. These "'prestige' or 'status' auctions" naturally take place during interactive brainstorming (Sutton & Hargadon, 1996, p. 705). This implies that members, before sharing or during the short transition from the alone to group session, process their ideas on their qualities to decide which to share first. This, as an eliminative process key to reducing cognitive burdens (Simon, 1955), would make the next round of idea evaluation cognitively less overwhelming and more effective (Haught-Tromp, 2017; Iyengar & Lepper, 2000).

H4: Hybrid group members will outperform all-noninteractive group members in the number of individually selected quality ideas evaluated for their (a) usefulness, (b) originality, and (c) overall quality.

In some previous studies (e.g., Putman & Paulus, 2009; Rietzschel et al., 2006), both all-interactive and all-noninteractive groups were not able to select ideas above chance level. However, Rietzschel et al. (2010, 2014) showed that, with explicit instruction to select "creative" ideas, groups tend to select more original but no less feasible ideas. These researchers noted that clearly communicating *creativity* to participants as the selection criterion for them to use contrasted with previous studies that asked participants to simply select *best* (e.g., Putman & Paulus, 2009) or *favorite* (e.g., Faure, 2004; Rietzschel et al., 2006) ideas. Asking participants to select *best* or *favorite* ideas may not have been sufficient to override what Mueller et al. (2012) call an implicit bias people have toward practicality and against creativity.

We extend these findings on the relationship between clearly communicated selection criteria and selection quality (Rietzschel et al., 2010, 2014) to the opposite direction toward usefulness. One reason for this direction is that to be creative is to produce something both original *and* useful (Stein, 1953). With the clear and emphatic communication to think critically during idea selection, we expect that the proportion of useful ideas will be higher among the selected ideas than among the nonselected ideas. Another reason for our idea selection criterion is that emphasis on usefulness well-aligns with the goal of idea selection in industrial contexts (see Cooper, 1990), on which our task is based. Even if we find the expected results, however, they will not necessarily suggest that selection of more useful ideas is due to the specific evaluative criterion to be critical, because the evaluative criterion does not vary across conditions. Nonselected ideas will be compared against only the individually selected ideas (see Method), given group discussion for group decision making will be only in the hybrid condition (see H6).

H5: In both hybrid groups and all-noninteractive groups, proportion of quality ideas will be higher for individually selected than nonselected ideas evaluated for their (a) usefulness, which in turn will positively affect (b) overall quality.

Finally, we anticipate hybrid groups will select higher-quality ideas during the subsequent group discussion. After the individual selection, hybrid group members will be asked to freely discuss and debate to select as a group their top ideas out of the individually selected ideas. The rationale is that because there will be a smaller number of ideas to consider (only nine ideas—three from each of the three members), it will likely be less cognitively demanding than having to choose from a larger number of options (Rietzschel et al., 2014). With fewer options, more cognitive resources will be available for careful consideration of each (Schwartz, 2004).

H6: After the initial individual idea selection, hybrid group members will select ideas of higher (a) usefulness, (b) originality, and (c) overall quality through free group discussion.

# Method

## Participants

The study was approved by the university IRB. Participants were 161 undergraduate students from a large Midwestern university in the United States. They received extra credit in a communication class for their participation. Eleven participants who did not follow instructions were excluded, resulting in a final sample of 150. Participants were randomly assigned to hybrid (36 groups, $n$ = 108) or all-noninteractive groups (14 groups, $n$ = 42). Hybrid groups followed seven brainstorming rules ("Defer judgment," "Encourage wild ideas," "Build on the ideas of others," "Stay focused on the topic," "One conversation at a time," "Be visual," and "Go for quantity, Brown, 2009; Kelley, 2001; Osborn, 1953; Putman & Paulus, 2009)[2]; all-noninteractive groups followed the same rules modified for them, which resulted in eliminating the "One conversation at a time" rule. For hybrid groups, three participants were in the lab. For all-noninteractive groups, there were only one or two participants in the lab. The three-person all-noninteractive groups were determined and aggregated in the order that these separate individuals' data were collected.

## Materials and Procedures

The presence of a trained facilitator and use of semiotic resources (a whiteboard, post-it notes, and markers) were the default (Brown, 2009; Kelley, 2001; Offner et al., 1996) in both conditions.

Seven facilitators took turns running the experimental sessions: Six were undergraduate research assistants selected by a communication professor to assist in lab operations. The facilitation was counter-balanced and randomly assigned to sessions. The first author facilitated four hybrid groups when research assistants were unavailable. Facilitators trained by engaging in several pilot sessions. While leading, the facilitator had a guideline packet at hand explaining the rule enforcement with examples of what to say. Part of these explanations followed the example of Putman and Paulus (2009). The first author watched the pilot sessions and provided detailed feedback, so that level and style of facilitation could be largely equivalent. This study constituted one-half of a larger laboratory session that involved two studies.

### *Hybrid Groups*

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[2] This study constituted one-half of a larger laboratory session that involved two studies. Four ("Defer judgment," "Encourage wild ideas," "Build on the ideas of others," and "Go for quantity") of the seven rules were the same as Osborn's (1953) four rules ("Judicial judgment is ruled out," "Free-wheeling is welcomed," "Combination and improvement are sought," and "Quantity is wanted"). The three additional rules ("Stay focused on the topic," "One conversation at a time," and "Be visual") were related to the other study. These three rules have been found to aid idea generation by boosting focus. "One conversation at a time" is irrelevant without interaction.

Upon entering the lab, participants completed informed consent, after which they were randomly assigned to either hybrid or all-noninteractive condition. They sat at a table in front of a whiteboard and received a marker, post-it notes of a certain color (each participant per session was given a different color), and a rule sheet. After viewing a two-minute video illustration of group brainstorming (Cheung, 2017), they completed a two-minute warm-up exercise with a different topic. After this warm-up, the facilitator presented the main problem:

> Create the best backpack in the world for college students like you! You are a member of a product development team at a huge sportswear company. The sales are down 50%. The future of your company hinges on your creative ideas!

The topic was carefully selected based on pilot testing and consideration of a proper difficulty level given the undergraduate participants' familiarity with the object. For the main brainstorming task, participants in the hybrid condition generated ideas individually for 6 minutes, and then brainstormed together for 12 minutes. This ensured that members in the hybrid condition started interacting only after having generated ideas individually. For hybrid groups, the facilitator was outside the lab only during noninteractive brainstorming (6 minutes). During interaction, participants freely took turns sharing their individually generated ideas, while at the same time generating more ideas. Six minutes was selected, as (1) Kohn and Smith (2011) demonstrated that idea generation slows down considerably within 5 minutes, which we also observed during the pilot sessions, (2) the duration of each session (6 or 12 minutes) was pilot-tested several times to ensure that they were adequate in length, and (3) we adopted the same 1:2 ratio from Girotra et al. (2010), who used a hybrid of a 10-minute individual brainstorming session followed by a 20-minute interactive brainstorming session.

When the time was up, participants were asked to be completely critical and select their individual top three ideas in solitude. Then participants in this hybrid condition were asked to come together as a group to freely debate and select the top three ideas of the group. During this discussion within hybrid groups, there was no emphasis on criticalness. After completing the survey, participants were given debriefing forms and thanked.

### *All-Noninteractive Groups*

All-noninteractive groups were the same as the hybrid condition, except for a few adjustments. First, any interactive elements and facilitation by the facilitator were excluded. All-noninteractive group members were either alone or did not interact when there was another participant in the room. These participants used post-it notes and markers to record their ideas but did not use the whiteboard. The facilitator was outside the room during the entire noninteractive brainstorming (18 minutes). Second, two rules were modified ("Welcome wild ideas" instead of "Encourage wild ideas" and "Build on previous ideas" in place of "Build on the ideas of others.") Finally, all-noninteractive participants did not have a group discussion after the critical individual selection of their top three ideas.

## Measures

To account for non-independence among members in hybrid groups, multilevel modeling with group ID as a random factor with correlated error variance was used for analysis of level-1 outcome variables (i.e., the survey data, idea quantity and quality). Fitting models with the following equations, we specify condition (hybrid or all-noninteractive group) as the level-2 predictor (RQ1, RQ2, and H1-H4),

$$Outcome_{ij} = \gamma_{00} + \gamma_{01}\mathrm{hybrid}_j + u_{0j} + e_{ij};$$

where $i$ = individual, and $j$ = group, respectively; individual selection (or nonselection) as the level-1 predictor (H5),

$$Outcome_{ij} = \gamma_{00} + \gamma_{10}\text{individual selection}_{ij} + u_{0j} + e_{ij};$$

where $i$ = phase (before or after individual selection), $j$ = group; and having an additional group discussion (or not) within hybrid groups as the level-1 predictor (H6),

$$Outcome_{ij} = \gamma_{00} + \gamma_{10}\text{additional group discussion}_{ij} + u_{0j} + e_{ij},$$

where $i$ = phase (before or after group discussion), and $j$ = group, respectively.

***Motivational Benefits***

**Goal Clarity**. Three items (e.g., “Our group had one clear goal”) measured goal clarity on a scale of *1* (*strongly disagree*) to *7* (*strongly agree*). The items were adopted from a *vision* scale by García-Morales et al. (2006). Questions were modified for all-noninteractive groups (e.g., “I had a clear goal during the task”). Reliability was strong ($Rwg$ = .77; for interpretation, see LeBreton & Senter, 2008). See Appendix A for survey items.

**Engagement.** Engagement was comprised of 7 items ($Rwg$ = .61) measuring *vigor* and *absorption*. Three items (e.g., “During the task, my group was full of energy”) were adopted from Salanova et al.’s (2003) vigor scale, and measured on a 7-point scale from *1* (*strongly disagree*) to *7* (*strongly agree*). For all-noninteractive groups, questions were modified (e.g., “During the task, I was full of energy”). Reliability was moderate ($Rwg$ = .54). *Absorption* was comprised of four items (e.g., “My group was immersed in the task”) adopted from the absorption scale (Salanova et al., 2003) and measured on the same 7-point scale as *vigor*. Items were modified (e.g., “I was immersed in the task”) for all-noninteractive groups. Reliability was moderate ($Rwg$ = .60).

**Task Attractiveness.** Four items (e.g., "I liked the guidelines for brainstorming in this group") adopted and modified from the *task attractiveness* scale (Estabrooks & Carron, 2000) were measured on a scale of *1* (*strongly disagree*) to *7* (*strongly agree*). Questions were modified for all-noninteractive groups (e.g., "I liked the guidelines for brainstorming"). Reliability was strong (*Rwg* = .74).

**Quantity**. Number of ideas generated by each participant was used to measure idea quantity. Unlike hybrid groups, all-noninteractive group participants would generate a few duplicate ideas because they were not aware of the ideas that others in the same all-noninteracting group generated. Only one of a duplicate idea was counted.

**Quality.** The number of ideas out of all nonselected ideas that were rated as "good" on usefulness was taken as the usefulness score for nonselected ideas. The number of ideas out of the three individually selected ideas that were "good" on usefulness was taken as the usefulness score for individually selected ideas. To compare the level of usefulness between nonselected and selected ideas (H5), the proportion (not the total number) of nonselected ideas "good" on usefulness was compared against the proportion of selected ideas "good" on usefulness. Measurement and comparisons of originality and overall quality were done in the same manner.

***Coding Scheme***. A total of 3,346 ideas by 150 participants were rated on usefulness and originality (Litchfield et al., 2011) using a scale from *1* (*very bad*) to *4* (*very good*). An idea with a score of 3 or above was *good* and 2 or below *bad* for each of the two criteria. Usefulness was content-analyzed by three independent coders and originality[3] by another three independent coders. The first round involving 250 ideas did not meet inter-coder reliability on usefulness (KALPHA = .668) and originality (KALPHA = .591). The next round with another 250 ideas

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[3] A practicing professional industrial designer with experience in backpack design reviewed the codebook and provided feedback, which was reflected in the codebook (Amabile, 1982).

had a KALPHA = .909 and .830, respectively. The coders then rated the remaining 2,846 ideas. Only ideas rated *good* on both usefulness and originality were counted as ideas *good* on overall quality[4].

## Results

### Motivational Benefits

#### *Goal Clarity*

We hypothesized (H1) hybrid group members ($M$ = 6.32) would perceive their goal with greater clarity than all-noninteractive members ($M$ = 5.93). H1 was supported, $\gamma_{01}$ = .40, $df$ = 48, $t$ = 2.54, $p$ = .015. Intraclass correlation (ICC)[5] was .07, indicating that approximately 7% of total variance in perceived goal clarity was attributable to group differences. The effect size was an increase of 0.50 standard deviation (*SD*)[6].

**Table 1**

*Descriptive Statistics (Means and Standard Deviations) of Outcome Variables.*

| Variable | Hybrid (n = 108, 36 groups) | | All-noninteractive (n = 42, 14 groups) | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Non-idea benefits | | | | |
| Goal clarity | 6.32 | 0.78 | 5.93 | 0.86 |
| Engagement | | | | |
| Vigor | 5.38 | 1.12 | 4.88 | 0.98 |
| Absorption | 5.50 | 0.88 | 4.84 | 1.03 |
| Task attractiveness | 6.18 | 0.83 | 5.70 | 0.91 |
| Generation of ideas | | | | |
| Quantity of ideas | 16.85 | 6.71 | 22.86 | 12.40 |
| Quality (nonselected) | | | | |
| Usefulness | 7.07 | 3.32 | 11.36 | 8.22 |

[4] Our filtering method, modified and adopted from the industrial product development process (Cooper, 1990), fits the type of task in Studies I and II and is consistent with the criteria used by innovative industrial product designers that demand ideas to simultaneously meet all key attributes of a creative solution (Brown, 2009).

[5] $\tau^2 / (\tau^2 + \sigma^2)$

[6] The value of $\gamma_{01}$ divided by the pooled standard deviation of the outcome variable (e.g., .40/.80 = .50 for goal clarity).

| | | | | |
|---|---|---|---|---|
| Originality | 9.28 | 3.94 | 12.60 | 8.34 |
| Overall quality | 6.67 | 2.90 | 8.21 | 7.06 |
| Selection of ideas | | | | |
| Quality (individually selected) | | | | |
| Usefulness | 2.20 | 0.77 | 1.74 | 0.96 |
| Originality | 1.59 | 0.83 | 1.76 | 0.88 |
| Overall quality | 1.30 | 0.87 | 1.21 | 0.95 |
| Quality (selected as a group) | | | | |
| Usefulness | 2.42 | 0.69 | - | - |
| Originality | 2.11 | 0.81 | - | - |
| Overall quality | 1.89 | 0.78 | - | - |

**Table 2**

*HLM Estimates of the Hybrid-Group Effects (Level-2 Predictor) on Non-Idea Benefits in Comparison to All-Noninteractive Groups (H1-H3).*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| Goal clarity | | | | | | |
| Intercept ($\gamma_{00}$) | 6.32 | | | | | |
| Hybrid condition ($\gamma_{01}$) | 0.40 | 0.16 | 2.54 | 48 | .015* | |
| Between-group variances ($\tau^2$) | | | | | | 0.05 |
| Within-group variances ($\sigma^2$) | | | | | | 0.60 |
| Vigor | | | | | | |
| Intercept ($\gamma_{00}$) | 5.38 | | | | | |
| Hybrid condition ($\gamma_{01}$) | 0.50 | 0.24 | 2.08 | 48 | .043* | |
| Between-group variances ($\tau^2$) | | | | | | 0.27 |
| Within-group variances ($\sigma^2$) | | | | | | 0.91 |
| Absorption | | | | | | |
| Intercept ($\gamma_{00}$) | 5.50 | | | | | |
| Hybrid condition ($\gamma_{01}$) | 0.67 | 0.18 | 3.61 | 48 | <.001*** | |
| Between-group variances ($\tau^2$) | | | | | | 0.08 |
| Within-group variances ($\sigma^2$) | | | | | | 0.78 |
| Task attractiveness | | | | | | |
| Intercept ($\gamma_{00}$) | 6.18 | | | | | |
| Hybrid condition ($\gamma_{01}$) | 0.48 | 0.17 | 2.88 | 48 | .006** | |

| | |
|---|---|
| Between-group variances ($\tau^2$) | 0.06 |
| Within-group variances ($\sigma^2$) | 0.67 |

* $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed).

***Engagement***

We hypothesized that hybrid members would have higher *vigor* (H2-a) and *absorption* (H2-b) than all-noninteractive members. *Vigor* was higher for hybrid members ($M = 5.38$) than for all-noninteractive members ($M = 4.88$), $\gamma_{01} = 0.50$, $df = 48$, $t = 2.08$, $p = .043$, ICC = .23, and the effect was a 0.46 *SD* increase. Thus, H2-a was supported. *Absorption* was higher for hybrid members ($M = 5.50$) than for all-noninteractive members ($M = 4.84$), $\gamma_{01} = .67$, $df = 48$, $t = 3.61$, $p < .001$, ICC = .10, and the effect size was 0.72 *SD* favoring hybrid members. Thus, H2-b was supported.

***Task Attractiveness***

H3 stated that hybrid members ($M = 6.18$) would perceive stronger *task attractiveness* compared to all-noninteractive members ($M = 5.70$). H3 was supported, $\gamma_{01} = 0.48$, $df = 48$, $t = 2.88$, $p = .006$, ICC = .08, with an effect size of 0.56 *SD* increase.

**Generation of Ideas**

***Quantity***

Quantity of ideas all-noninteractive members generated ($M = 22.86$) was significantly greater than hybrid members ($M = 16.85$), $\gamma_{01} = 6.01$, $df = 48$, $t = 3.42$, $p = .001$, ICC = .12, with an effect size of 0.69 *SD* increase. The answer to RQ1 (if all-noninteractive brainstorming would generate ideas of greater quantity) was positive.

**Table 3**

*HLM Estimates of the Hybrid-Group Effects (Level-2 Predictor) on Idea Generation in Comparison to All-Noninteractive Groups (RQ1 and RQ2).*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| Quantity | | | | | | |
| Intercept ($\gamma_{00}$) | 16.85 | | | | | |
| Hybrid condition ($\gamma_{01}$) | -6.01 | 1.76 | -3.42 | 48 | .001** | |
| Between-group variances ($\tau^2$) | | | | | | 8.94 |
| Within-group variances ($\sigma^2$) | | | | | | 66.48 |
| Usefulness (nonselected) | | | | | | |
| Intercept ($\gamma_{00}$) | 7.07 | | | | | |
| Hybrid condition ($\gamma_{01}$) | -4.28 | 0.94 | -4.56 | 148 | <.001*** | |
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 26.66 |
| Originality (nonselected) | | | | | | |
| Intercept ($\gamma_{00}$) | 9.28 | | | | | |
| Hybrid condition ($\gamma_{01}$) | -3.32 | 1.00 | -3.30 | 148 | .001** | |
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 30.50 |
| Overall Quality (nonselected) | | | | | | |
| Intercept ($\gamma_{00}$) | 6.67 | | | | | |
| Hybrid condition ($\gamma_{01}$) | -1.55 | 0.81 | -1.91 | 148 | .058 | |
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 19.89 |

* $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed).

### *Quality of Non-Selected Ideas*

Quality of ideas was evaluated on usefulness, originality, and overall quality. The number of non-selected ideas rated *good* on usefulness was greater for all-noninteractive members ($M$ = 11.36) than for hybrid members ($M$ = 7.07), $\gamma_{01} = 4.28$, $df = 148$, $t = 4.56$, $p < .001$, ICC < .01; the effect was a 0.83 *SD* increase. The answer to RQ2-a was positive. The number of non-selected ideas rated *good* on originality was greater for all-noninteractive members ($M$ = 12.60) than for hybrid members (*M* = 9.28), $\gamma_{01}$ = 3.32, *df* = 148, *t* = 3.30, *p* = .001, ICC < .01; the effect size was an increase of 0.61 *SD*. The answer to RQ2-b (if all-noninteractive groups would generate more original ideas) was positive. The number of non-selected ideas rated as *good* on overall quality (*good* on both criteria) was greater for all-noninteractive members (*M* = 8.21) than for hybrid members (*M* = 6.67), $\gamma_{01}$ = 1.55, *df* = 148, *t* = 1.91, *p* = .058, ICC = .12, with an effect size of 0.35 *SD* increase. The answer to RQ2-c (if all-noninteractive groups would generate more overall high-quality ideas) was marginally positive.

**Selection of Ideas**

Quality of individually selected ideas was evaluated on usefulness, originality, and overall quality to compare between the hybrid and all-noninteractive conditions (H4). The number of individually selected ideas rated *good* on usefulness for hybrid members (*M* = 2.20) was greater than for all-noninteractive members (*M* = 1.74), $\gamma_{01}$ = 0.47, *df* = 148, *t* = 3.09, *p* = .002, ICC < .01, and the effect was a 0.57 *SD* increase; H4-a was supported (Table 4). An average hybrid member did not individually select more ideas *good* on originality (*M* = 1.59) than an average all-noninteractive member (*M* = 1.76), $\gamma_{01}$ = -0.17, *df* = 48, *t* = -1.02, *p* = .311, ICC = .08; H4-b was unsupported. There were no more individually selected ideas rated *good* on overall quality for hybrid (*M* = 1.29) than all-noninteractive members (*M* = 1.21), $\gamma_{01}$ = .08, *df* = 148, *t* = 0.51, *p* = .614, ICC < .01; H4-c was unsupported.

**Table 4**

*HLM Estimates of the Hybrid-Group Effects (Level-2 Predictor) on Individual Idea Selection in Comparison to All-Noninteractive Groups (H4).*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| Usefulness (individually selected) | | | | | | |
| Intercept ($\gamma_{00}$) | 2.20 | | | | | |
| Hybrid condition ($\gamma_{01}$) | 0.47 | 0.15 | 3.09 | 148 | .002** | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 0.69 |
| Originality (individually selected) | | | | | | |
| Intercept ($\gamma_{00}$) | 1.59 | | | | | |
| Hybrid condition ($\gamma_{01}$) | -0.17 | 0.17 | -1.02 | 48 | .311 | |
| Between-group variances ($\tau^2$) | | | | | | 0.06 |
| Within-group variances ($\sigma^2$) | | | | | | 0.66 |
| Overall Quality (individually selected) | | | | | | |
| Intercept ($\gamma_{00}$) | 1.30 | | | | | |
| Hybrid condition ($\gamma_{01}$) | 0.08 | 0.16 | 0.51 | 148 | .614 | |
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 0.79 |

* $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed).

The usefulness and overall quality criteria were used to compare the quality of individually-selected versus nonselected ideas (H5). The comparisons were done within either hybrid or all-noninteractive groups, respectively. In hybrid groups, the proportion of useful ideas among individually selected ideas (*M* = .74) was higher than nonselected ideas (*M* = .44), $\gamma_{10}$ = .30, *df* = 179, *t* = 10.34, *p* < .001, ICC = .08. The effect was a 1.30 *SD* increase; H5-a was supported for hybrid groups (Table 5). In hybrid groups, the proportion of ideas *good* on overall quality among individually selected ideas (*M* = .43) was higher than nonselected ideas (*M* = .36), $\gamma_{10}$ = .07, *df* = 179, *t* = 2.45, *p* = .015, ICC = .01, and the effect was a 0.32 *SD* increase; H5-b was supported for hybrid groups. The better overall quality of the ideas individually selected by an average hybrid group member (H5-b) seems to be due to them selecting more useful (H5-a) yet no less original ideas. In all-noninteractive groups, the proportion of useful ideas among individually selected ideas (*M* = .58) was not significantly higher than nonselected ideas (*M* = .49), although there was a trend in the positive direction, $\gamma_{10}$ = .09, *df* = 82, *t* = 1.67, *p* = .098, ICC < .01, and the effect was a 0.35 *SD* increase; H5-a was not supported for all-noninteractive groups. In all-noninteractive groups, the proportion of ideas *good* on overall quality among individually selected ideas ($M$ = .40) was not higher than nonselected ideas ($M$ = .34), $\gamma_{10}$ = .07, $df$ = 82, $t$ = 1.20, $p$ = .235, ICC < .01, and the effect was a 0.28 *SD* increase; H5-b was unsupported for all-noninteractive groups.

**Table 5**

*HLM Estimates of the Individual Selection Effects (Level-1 Predictor) on the Proportion of Quality Ideas in Comparison to Nonselected Ideas for Each Condition (H5).*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| Hybrid Groups | | | | | | |
| Usefulness | | | | | | |
| Intercept ($\gamma_{00}$) | .44 | | | | | |
| Individual selection ($\gamma_{10}$) | .30 | .03 | 10.34 | 179 | <.001*** | |
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 0.05 |
| Originality (not hypothesized) | | | | | | |
| Intercept ($\gamma_{00}$) | .56 | | | | | |
| Individual selection ($\gamma_{10}$) | -.03 | .03 | -0.84 | 179 | .405 | |
| Between-group variances ($\tau^2$) | | | | | | <0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 0.05 |
| Overall Quality | | | | | | |
| Intercept ($\gamma_{00}$) | .36 | | | | | |
| Individual selection ($\gamma_{10}$) | .07 | .03 | 2.45 | 179 | .015* | |
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 0.05 |
| All-Noninteractive Groups | | | | | | |
| Usefulness | | | | | | |
| Intercept ($\gamma_{00}$) | .49 | | | | | |
| Individual selection ($\gamma_{10}$) | .09 | .06 | 1.67 | 82 | .098 | |
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 0.07 |
| Originality (not hypothesized) | | | | | | |
| Intercept ($\gamma_{00}$) | .54 | | | | | |
| Individual selection ($\gamma_{10}$) | .05 | .05 | .91 | 69 | .368 | |
| Between-group variances ($\tau^2$) | | | | | | <0.01 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Within-group variances ($\sigma^2$) | | | | | | 0.06 |
| Overall Quality | | | | | | |
| Intercept ($\gamma_{00}$) | .34 | | | | | |
| Individual selection ($\gamma_{10}$) | .07 | .05 | 1.20 | 82 | .235 | |
| Between-group variances ($\tau^2$) | | | | | | < 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 0.06 |

* $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed).

Only hybrid groups had a brief group discussion after the individual idea selection to decide the top three ideas at the group level (Table 6). So, we tested the discussion effect for hybrid groups based on the usefulness, originality, and overall quality of ideas they selected (H6). In hybrid groups, number of ideas selected through group discussion rated *good* on usefulness ($M$ = 2.42) was greater than their individual selection ($M$ = 2.20), $\gamma_{10}$ = 0.21, $df$ = 395, $t$ = 3.14, $p$ = .002, ICC = .34, and the effect was a 0.28 *SD* increase; H6-a was supported. In hybrid groups, group discussion also resulted in more original ideas ($M$ = 2.11) than individual selection ($M$ = 1.61), $\gamma_{10}$ = 0.50, $df$ = 395, $t$ = 6.60, $p$ < .001, ICC = .33, and the effect size was an increase of 0.80 *SD*; H6-b received support. In hybrid groups, more of the three selected ideas were of higher overall quality after group discussion ($M$ = 1.89) than after individual selection ($M$ = 1.31), $\gamma_{10}$ = .57, $df$ = 395, $t$ = 7.01, $p$ < .001, ICC = .26, and the effect was a 0.66 *SD* increase; H6-c was also supported.

**Table 6.**

*HLM Estimates of the Group Discussion Effects (Level-1 Predictor) on Idea Selection in Comparison to the Preceding Individual Idea Selection (H6)*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| Usefulness | | | | | | |
| Intercept ($\gamma_{00}$) | 2.42 | | | | | |
| Group discussion ($\gamma_{10}$) | 0.21 | 0.07 | 3.14 | 395 | .002** | |
| Between-group variances ($\tau^2$) | | | | | | 0.19 |
| Within-group variances ($\sigma^2$) | | | | | | 0.37 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Originality | | | | | | |
| Intercept ($\gamma_{00}$) | 2.11 | | | | | |
| Group discussion ($\gamma_{10}$) | 0.50 | 0.08 | 6.60 | 395 | <.001*** | |
| Between-group variances ($\tau^2$) | | | | | | 0.23 |
| Within-group variances ($\sigma^2$) | | | | | | 0.47 |
| Overall Quality | | | | | | |
| Intercept ($\gamma_{00}$) | 1.89 | | | | | |
| Group discussion ($\gamma_{10}$) | 0.57 | 0.08 | 7.01 | 395 | <.001*** | |
| Between-group variances ($\tau^2$) | | | | | | 0.19 |
| Within-group variances ($\sigma^2$) | | | | | | 0.54 |

* $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed).

## Discussion

A hybrid of noninteractive and interactive FtF brainstorming is widely practiced in the industry (e.g., Amabile et al., 2014; Osborn, 1953; Sutton & Hargadon, 1996). However, no research in FtF settings has compared noninteractive-interactive to all-noninteractive brainstorming on (1) motivational benefits, (2) idea generation, and (3) idea selection (cf. Girotra et al., 2010). The operationalization of hybrid brainstorming in this study was noninteractive-then-interactive without the explicit request for the interaction phase that would likely be found in an organization. There was a trained facilitator during interaction for hybrid groups.

### Non-Idea Benefits

Hybrid groups, in comparison to all-noninteractive, resulted in enhanced goal clarity (*vision*) (H1); engagement, that is, *vigor* (H2-a) and *absorption* (H2-b); and *task attractiveness* (H3). Within the componential model of organizational creativity, synergistic extrinsic motivation is externally derived, but enhances the existing intrinsic motivation. Interaction within hybrid brainstorming can likewise be a synergistic extrinsic motivator. Thus, it does not seem to be a coincidence that experienced practitioners deliberately use interactive brainstorming as an idea generator *and* a motivator (e.g., Kelley, 2001; Sutton & Hargadon, 1996). More broadly, motivation and other non-idea effects from collective creative activities are beneficial to employees (for networking, well-being, Dennis & Reinicke, 2004; obtaining skill variety, Sutton & Hargadon, 1996; equitable decision making, Kramer et al., 1997; group/team cohesiveness, Henningsen & Henningsen, 2013; reinforcing organizational memory, Sutton & Hargadon, 1996). In the long run, these non-idea benefits could feed into group performance (for example, see Rodríguez-Sánchez et al., 2017). Further research could test if interactive-noninteractive brainstorming or alternating between the two modes of brainstorming would produce any non-idea benefits.

**Idea Generation**

In FtF settings, hybrid groups without a facilitator have been found to produce more ideas than all-interactive groups (Girotra et al., 2010; Rotter & Portugal, 1969) but fewer than all-noninteractive groups. When assisted by a trained facilitator, which is a normal industry practice (Kramer et al., 2001; Offner et al., 1996), all-interactive groups can be as productive as all-noninteractive groups (Kramer et al., 2001; Offner et al., 1996; Oxley et al. 1996). We compared the productivity of noninteractive-interactive hybrid groups in the presence of a trained facilitator with all-noninteractive groups. Even with a facilitator, our hybrid groups generated ideas of lower quantity (RQ1), usefulness (RQ2-a), originality (RQ2-b), and overall quality (RQ2-c, though marginally significant with $p$ = .058) than all-noninteractive groups. Given *quantity breeds quality* (Stroebe et al., 2010), it is not surprising that our all-noninteractive group members, who produced ideas of greater quantity, also produced ideas of greater quality than the hybrid group members. There may be multiple possible explanations for this productivity loss in our hybrid groups. There likely have been production blocking, which arises because members must take turns to share their ideas in a group (Diehl & Stroebe, 1987). Moreover, the time required for each member to share with other members ideas that they individually generated prior to interaction would have prevented hybrid groups from using all their time for idea generation. Insufficient facilitator training is another possibility. However, we argue that first, researchers need to look beyond the traditional productive-counterproductive discussion and address the situated nature of brainstorming (see Csikszentmihalyi & Sawyer, 2014; Nielsen & Miraglia, 2017). In real group or organizational contexts, some trade-off between idea-wise productivity and non-idea, socio-emotional benefits might be necessary. Second, interactive brainstorming would probably be most effective when a member of an organization, who has exhaustively generated ideas on their own and reached an impasse, seeks additional or breakthrough ideas (Sutton & Hargadon, 1996), which we have not operationalized.

## Idea Selection

### *Individual Selection: All-Noninteractive Versus Hybrid Groups*

Hybrid group members had more individually selected useful ideas (H4-a) than all-noninteractive groups, while there was no difference in originality (H4-b) nor in overall quality (H4-c). That noninteractive-interactive brainstorming seems to have an advantage in idea selection may carry a heavy implication for organizations that want to innovate, because selected ideas are the ones to be considered for development, elaboration, and implementation (Ahn & Van Swol, 2021).

Better individual idea selection by hybrid groups may be due to several reasons including, first, greater cognitive ease after voluntary pre-evaluation that helps simplify the decision task (Iyengar & Lepper, 2000; Simon, 1955). This cognitive ease interpretation is based on our reasoning that sometime before interaction starts, participants would have already processed their own ideas. This would help participants present more appealing ideas first, so that they could appear as or more competent than others (see status auction, Sutton & Hargadon, 1996; see also social comparison theory, Festinger, 1954).

Another likely reason is that hybrid group members had a bigger pool of high-quality candidate ideas to choose from. For example, even though an average all-noninteractive member generated more ideas of *good* overall quality (*M* = 8.21; see Table 1) than an average hybrid member (*M* = 6.67), an average hybrid group of three members together generated far more *good* overall quality ideas (6.67 x 3 = 20.01) than a single average all-noninteractive group member.

Third, hybrid group members observed in real time during interaction the reactions of other group members to each idea being proposed. This experience could have increased hybrid group members' acuity in idea evaluation. Despite the nonjudgmental brainstorming rules, spontaneous verbal (e.g., "Oh, I love that!") and nonverbal (e.g., nodding) communication may provide more reference points by which to judge idea quality (Kerr & Murthy, 2004). Observing this feedback, the members in our study could have formed a preliminary impression of each shared idea, which would then let them make a more objectively informed, updated judgment (see Elqayam & Evans, 2013) at a later time to select ideas individually.

Fourth, path dependence may be a reason for the difference (Girotra et al., 2010). Participants in the interactive phase after the solo session were exposed to others' ideas without prior information on the path by which those ideas were generated. Thus, participants in hybrid groups may have cognitively responded to ideas themselves, rather than to ideas *and* their history. In contrast, those in the all-noninteractive condition experienced the path by which the ideas were generated, which could have rendered them less able to judge from a more disinterested standpoint, as they evaluated only their own ideas, all of which they would already have formed some impression about.

Lastly, a social setting itself might have increased the sense of accountability (Lerner & Tetlock, 1999) and motivation to deliberate more. Relatedly, mere verbalizing of and hearing ideas during interaction could have increased attention on idea quality. We do not know from our data whether the ability of hybrid members to individually select better ideas than all-noninteractive members was due to either reduced cognitive burdens, having more alternatives, being less biased, or social feedback or motivation. Future research should tease out the sources of variation in the ability to detect more creative solutions.

Interestingly, findings in Putman and Paulus (2009) allow us to extend the advantage of going hybrid in idea selection to another combination of idea generation and selection. They showed that noninteractive individuals who later met and discussed the shared ideas made better selections than interactive individuals who likewise subsequently discussed the ideas as a group. Note that their noninteractive condition can also be referred to as hybrid in the sense that the selection process was done in groups. Comparing one's own individual ideas (noninteractive condition) with the ideas of others likely involved less assimilation-contrast effects than discussing interactively generated ideas (Hovland et al., 1957). Participants who interactively generated ideas (interactive condition) would already have had some judgment of each idea's worth (with a semblance of the said path dependence). This judgment, functioning as an anchor, could have undermined the potential benefit of group discussion in making better judgments. Communication from other members about an idea that is near one's own pre-formed judgment of the idea would have been assimilated to it, and communication at variance with their own impression would have been contrasted away from it. In contrast, participants who generated ideas alone would have come to learn about others' ideas for the first time during group discussion, thus unaffected by such pre-formed judgment. Another explanation is that, because open disagreement would have been more difficult among groups who had been brainstorming together and forming some bonds, any disagreement during group discussion in the noninteractive condition would have been more authentic. Authentic disagreement has been found to lead to deeper analysis and more unconventional solutions (Nemeth et al., 2001). Not only the hybrid of noninteractive-then-interactive brainstorming as in our data but also the hybrid of noninteractive brainstorming followed by group discussion as in Putman and Paulus (2009) benefits idea selection. This potentially indicates a high generalizability of the positive effect of a hybrid of noninteractive and interactive sessions on creative decision making.

***Nonselected Versus Individually Selected Ideas***

We tested, with a clear criterion to be critical, if there would be increased proportions of useful (H5-a)—and consequently high overall quality (H5-b)—ideas from individual selection in both conditions. For hybrid groups, individually selected ideas were more useful and of overall higher quality than nonselected ideas. For all-noninteractive groups, individually selected ideas showed a trend of being more useful ($p$ = .098), but not of higher overall quality, than nonselected ideas. There was a common pattern in both conditions that usefulness of selected ideas was higher than nonselected ideas (H5-a), while the effect sizes differed by nearly 1 *SD* (1.30 *SD* for hybrid and 0.35 *SD* for all-noninteractive groups). This seems to suggest that the difference in the effect sizes of usefulness primarily accounted for whether overall quality of selected ideas (H5-b) was significantly higher (for hybrid groups) or not (for all-noninteractive groups) than nonselected ideas.

Several previous studies seemingly without communicating clear criteria did not find a difference between nonselected and selected ideas (Faure, 2004; Putman & Paulus, 2009; Rietzschel et al., 2006). Our study had a clear criticalness criterion, and it is interesting to see that this strong criticalness criterion likely induced participants to individually select more useful (H4-a) but no less original ideas. This is analogous to Rietzschel et al. (2010, 2014) who communicated to participants a specific criterion (i.e., “creativity”) and found results in that direction—selecting more original but no less feasible ideas. The present study extended their findings in the direction to criticalness and usefulness. Nonetheless, data do not suggest a causal link between our specific emphasis on critical selection and selecting more useful ideas, since we did not manipulate the selection criteria.

When evaluating creative ideas, members may not have many relevant past experiences to base judgment on, because by definition, creative ideas are new to some degree (Stein, 1953). Having few relevant reference points would make the evaluation difficult and its result inaccurate. Here, clear criteria would enable more concrete mental simulation of events based on the idea. Clear criteria could also prime us to restrict the search space in memory and facilitate finding a relevant anchor within it, with which evaluation and selection would become easier (see Schwartz, 2004).

### *Group Discussion in Hybrid Groups*

Among hybrid groups, after a brief, free group discussion following critical individual selection, participants as a group chose ideas that were more useful (H6-a), original (H6-b), and of higher overall quality (H6-c) than their individually selected ideas. Similarly to some of the potential explanations for H4, we interpret these results as indicating an effect of reduced cognitive burdens resulting from multiple individual prior assessments and/or having to compare a smaller number of ideas during group discussion than individual selection. Since there was no instruction to be critical for this group discussion, we do not think the presumed effect of being particularly critical during the preceding individual selection period carried over to this stage. More research is needed to disentangle these effects.

### *Applied Questions*

Finally, that hybrid structures can enhance idea generation (Korde & Paulus, 2017; Osborn, 1953; Sutton & Hargadon, 1996) as well as selection (Girotra et al., 2010; Putman & Paulus, 2009) prompts us to discuss, briefly, what an ideal creative procedure might be like. From a cognitive perspective, one might be electronic brainstorming in an adequately large group (e.g., four or more, Gallupe et al., 1992; eight or more, DeRosa et al., 2007), in which there is alternation between solitary and collaborative sessions. Since members can work simultaneously, electronic brainstorming notably reduces production blocking (Gallupe et al., 1991, 1992), which Diehl and Stroebe (1987) suggested as a foremost cause of productivity loss during FtF interactive brainstorming. Deciding upon an adequate group size would be necessary to maximize anonymity that increases with group size, so that evaluation apprehension may be decreased, and minimize the temptation to free ride (social loafing), which may also increase with group size (Gallupe et al., 1992). Unless members need basic topical knowledge to spark ideas (see Dugosh & Paulus, 2005), it might be helpful to begin with individual ideation to allow members to generate their own unique ideas without the biasing effects of exposure to others' ideas (see Baron, 2005). One reason for alternation is that, although noninteractive brainstorming is highly productive, a subsequent interactive brainstorming can provide additional and breakthrough ideas as members with diverse cognitive styles and expertise participate (Stroebe & Diehl, 1994). The benefit will be even greater when individuals have already exhaustively generated ideas and called for a brainstorming meeting (Sutton & Hargadon, 1996). Another reason is that social stimulation may occur due to exposure to a high performance standard

(Paulus & Dzindolet, 1993). At some point another solitary session would be useful to allow individuals to reflect on the ideas shared by other members, without any possible distraction of the collaborative process (Pinsonneault et al., 1999).

With a high number of ideas generated in such a process, selecting the best idea(s) will be a challenge. However, either as individuals or as a group, during idea generation members will be provided access to the ideas already generated and continue generating new ideas or building on prior ideas (Gallupe et al., 1991). This facilitates focusing on more promising ideas and thereby spontaneously eliminating many other options (Harvey & Kou, 2013). Then, at some point the individual members as independent judges could be asked to highlight those ideas they considered the best (Amabile, 1982; Brown, 2009), and the high-scoring ideas could be selected, developed, and implemented (Cooper, 1990). Lastly, given the ubiquitous uncertainty inherent in creative projects, it will be necessary to update and revise beliefs about the idea or product based on iterative trials and errors throughout idea generation, selection, and implementation (Brown, 2009; Elqayam & Evans, 2013).

Besides the cognitive concerns, however, we should also consider social-affective and cultural-normative aspects. There is evidence FtF ideation excels electronic brainstorming in promoting group well-being (e.g., reinforcing the creative culture and helping socializing) and member support (e.g., creating status auctions and knowledge networks) (Dennis & Reinicke, 2004; for review, see Maaravi et al., 2021). Also, during idea selection and implementation, a transition to FtF interaction may be needed to effectively visualize ideas particularly if the project involves physical products.

## Limitations

This study has several limitations. First, most importantly, Sutton and Hargadon (1996) reported that interactive brainstorming provides the critical moments to get *unstuck* from an impasse to individuals who have been wrestling with a difficult problem for protracted periods. This may be one of the most important benefits of hybrid brainstorming that our study did not test. Second, we have not tested the interactive-then-noninteractive hybrid brainstorming. Without more comprehensive comparisons, it is not possible to determine the unique effects of the hybrid experience versus others. Third, we had a facilitator for the interaction phase of the hybrid condition. This may have increased external validity, given the presence of a facilitator is a widely accepted practice in the industry (Kelley, 2001; Osborn, 1953), however, at the expense of internal validity. For example, the presence of a facilitator in the lab during brainstorming could have had an influence on the self-report ratings in the hybrid condition. Fourth, it is possible that the brief, free discussion to select ideas among hybrid group members affected their reported motivational effects, although participants were asked to answer the questionnaire specifically regarding the idea generation phase. Fifth, the study design did not allow for a comparison between hybrid and all-noninteractive brainstorming on the effect of group discussion on selection. Lastly, we did not manipulate the evaluative criterion.

**Conclusion**

Hybrid brainstorming led to greater perceived motivation as it creates a clearer goal orientation, greater engagement (*vigor* and *absorption*), and stronger *task attractiveness* compared to all-noninteractive brainstorming. Thus, we argue that interactive or hybrid brainstorming can be an example of a synergistic extrinsic motivator (Amabile & Pratt, 2016). All-noninteractive groups generated more and better ideas than hybrid groups with a trained facilitator. Hybrid group members individually selected a greater number of useful ideas than all-noninteractive group members. The proportions of individually selected ideas in both conditions showed trends of being higher in usefulness than nonselected ideas. That the ideas were better particularly in usefulness may be due to our emphasis on being critical during individual idea selection. Additionally, hybrid groups had a free discussion and selected, as a group, ideas that were better in usefulness, originality, and overall quality than their individually selected ideas.

Our findings suggest that it may be a false dilemma to consider abandoning one mode of idea generation (e.g., all-interactive, or "real," groups) in favor of the other (e.g., all-noninteractive, or "nominal," groups) given the different relative advantages individuals and groups have. Certain hybrids of noninteractive and interactive modes appear beneficial for idea selection.

**Study II: A Reversed Serial-Order Effect for Decisions in Creative Processes**

## Abstract

The serial-order effect of increasing originality over time is one of the most robust findings in modern psychology. The effect is based on cognitive associative theory and spreading activation, as mental association takes place in sequential order from commonly (closely) to unusually (distantly) related semantic concepts stored in our long-term memory. Based on the serial-order effect, researchers for decades have suggested that we endure through a lengthy group session and pay closer attention to later solutions. Using the ecologically more valid individual-then-interactive hybrid brainstorming paradigm, multilevel linear modeling, and a comprehensive set of performance metrics, we demonstrate a “reversed” serial-order effect. First, solution quality by both count and proportion during interaction peaked early and quickly decayed. This reversed serial-order effect implies that meeting for a shorter time and looking into early solutions may lead to a better decision—if the interaction came after individual solution generation. We also found that the rate of solution diversity increase dropped steeply, yet its momentum remained at a low level. This suggests that extended interaction after individual solution generation could bring greater solution diversity rather than higher overall quality. Second, we found that the updated, cognitively constrained norm for solution generation, which likely narrows the scope of search, led to greater idea quantity, quality, and diversity than the traditional, unconstrained norm. In sum, Study II challenges simple traditional applications of cognitive associative theory and call for attention to the specific organizational contexts in which collective problem solving and decision making take place.

Modern creative problem solving and decision making generally do not take place in a social vacuum, but in specific group or organizational settings (Paulus et al., 2015). A ubiquitous business best practice, the group brainstorming technique following the four noncritical rules ("Defer judgment," "Encourage wild ideas," "Go for quantity," and "Build on the ideas of others"; Osborn, 1953) has provided one such social setting. Its noncritical norm promotes a focus on associating as many semantically distant concepts (Mednick, 1962) as possible and expressing them in an *unconstrained* fashion to obtain original solutions (Nemeth et al., 2004).

Since brainstorming's inception, however, researchers have commonly found the "serial-order effect" in which highly original solutions tend to appear only after some time of generating more mundane ideas (Christensen et al., 1957; Johnson & D'Lauro, 2018; Phillips & Torrance, 1977). This poses a considerable dilemma in real-world contexts: Obtaining highly innovative solutions is likely to be predicated upon commitment to a lengthy group session, whereas social processes necessary for innovation (e.g., cross-disciplinary collaboration), as well as the various job demands that keep employees in business organizations busy "fighting fires" (Andrews & Smith, 1996, p. 178) make time a highly scarce resource for the organization and employees (Acar et al., 2019; Amabile & Pratt, 2016; Binnewies & Wörnlein, 2011).

Another question critical to group creative problem solving has been whether the complete promotion of *unconstrained* association and expression of ideas is actually conducive to generating better solutions. Traditionally, constraints were thought to inhibit creative thinking. Recently, however, cognitively *constraining* norms (e.g., "Criticize other members"), which apparently contradicts the traditional, noncritical norm, have increasingly been reported to enhance the generation of creative solutions (e.g., Levine et al., 2016; Medeiros et al., 2014; Nemeth et al., 2004).

However, we noted that these reported studies on (1) the serial-order effect and (2) the cognitive constraint effect used either all-individual or all-interactive sessions. Both of these, in fact, significantly differ from group/organizational practices (Korde & Paulus 2017; Paulus et al., 2015; Sutton & Hargadon, 1996), where employees normally seek further ideas from their colleagues only after thinking on a problem on their own for some time. This form of group problem solving is referred to as hybrid brainstorming (Girotra et al., 2010; Korde & Paulus, 2017). No known studies have investigated the above two topics regarding hybrid brainstorming.

Confidence in assessment of solution *quality* will be central to our hypothesis tests. Most prior research on the over-time change of *quality* has relied on one (e.g., *creativity*) or two (e.g., *originality* and *feasibility*) criteria. In order to examine more comprehensively the temporal course of change in solution *quality*, we utilize Rietzschel et al.'s (2010) evaluation method and test *quantity*, *originality*, and the intersections between *originality and feasibility* (*O-F*) and among *originality, usefulness, and feasibility* (*O-U-F*) for each quarter during interaction.

Our experiment demonstrates that, when individuals generate solutions together after having generated solutions alone, solution *quality* is higher when generated earlier during the group session. This reverses the serial-order effect during group brainstorming. We then find that the cognitively *constrained* condition outperforms the *unconstrained* condition during hybrid brainstorming, though we find no evidence of mediation through productivity during the individual session that precedes the group session. Below we briefly review the literature on hybrid brainstorming and develop our hypotheses.

**Hybrid Brainstorming**

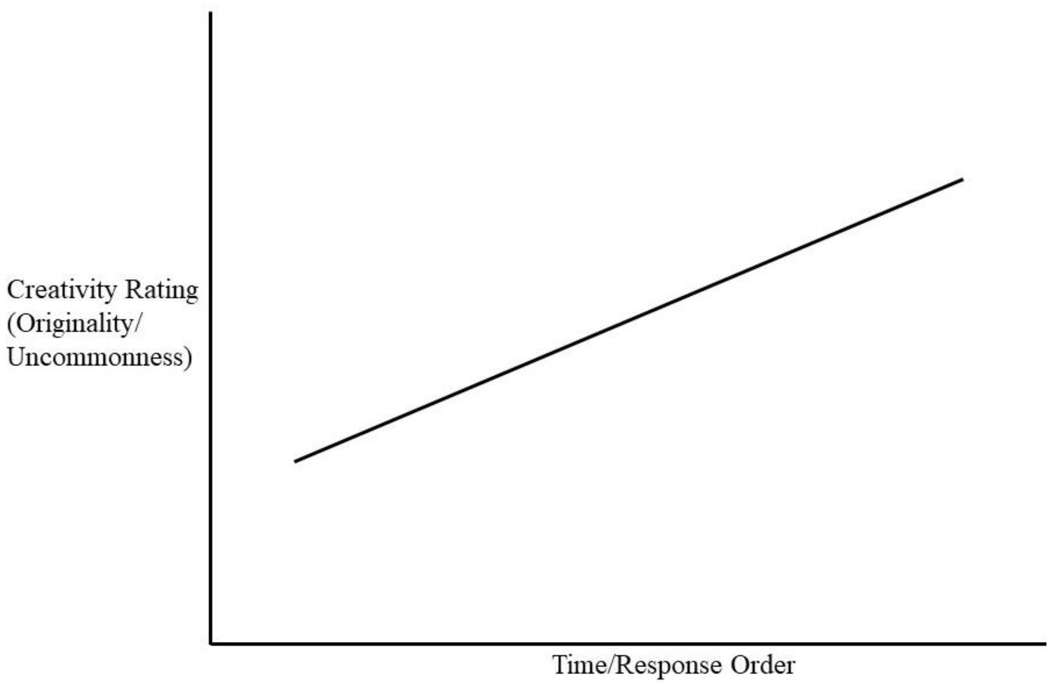
First, hybrid brainstorming has exceptionally high ecological validity compared with all-individual or all-interactive brainstorming: Practitioners have claimed that individual efforts to exhaustively generate potential solutions on their own should precede interactive brainstorming for the interaction to be effective (Osborn, 1953; Sutton & Hargadon, 1996). Second, relatedly, Korde and Paulus (2017) found that under certain conditions, hybrid groups do generate more solutions than all-interactive or all-noninteractive groups (see also Girotra et al., 2010). Third, interaction in groups, a part of hybrid brainstorming, brings several non-idea benefits (e.g., satisfaction, networking, training; Dennis & Reinicke, 2004; Sutton & Hargadon, 1996). Despite its obvious strengths, the hybrid paradigm has received surprisingly little research attention (Korde & Paulus, 2017). We now investigate how hybrid brainstorming sheds a new light on some key implications of the cognitive associative theory, which underlies any creative problem solving (Mednick, 1962).

## Hypotheses

### *Until the Last Second?*

Cognitive models for creative problem solving underpinned by associative theory, for example, Search for Ideas in Associative Memory model (Nijstad & Stroebe, 2006) and the matrix model (Brown et al. 1998), commonly dictate concepts stored in long-term memory that are semantically more proximal or more strongly tied are more likely to be readily activated during search. Typically, one would first think of ideas that are more common and obvious, and afterwards ones that are less salient or more unusual in the network. This is the "serial-order effect"—the spreading activation in semantic memory (Collins & Loftus, 1975) that causes later ideas to be more creative than earlier ones, while the number of ideas generated decreases over time (Christensen et al., 1957). On graphs with X axis representing time and Y axis representing *originality*, previous studies consistently demonstrated increases over time of *originality*—tied with decrease of *feasibility*—during brainstorming. Findings supportive of the serial-order effect have, since its discovery by J. P. Guilford and colleagues (Christensen et al., 1957), been one of the oldest and most robust in modern creativity research. The same pattern was observed whether researchers measured *originality* as number of solutions independent raters judged as original (see Johns et al., 2001; Parnes, 1961), proportion of original solutions (number of original solutions divided by *quantity*, see Christensen et al., 1957; Milgram & Rabkin, 1980; Runco, 1986; Ward, 1969), or mean rating on an *originality* scale (see Baruah & Paulus, 2016; Beaty & Silvia, 2012; Phillips & Torrance, 1977).

**Figure 1**
*A typical increase in solution originality over time from non-hybrid sessions*




The "clear" implications have been that "longer times" per topic "are more favorable" (Christensen et al., 1957, p. 88), "time spent in responding to these items was a stable characteristic" of participants' "performance" (Ward, 1969, p. 877), and "a short brainstorming session may be undesirable if highly original ideas are needed" (Johnson & D'Lauro, 2018, p. 191). Given *originality* is the hallmark of creative solution (Nijstad et al., 2010), the expected course of action is lengthier brainstorming. Additionally, during decision making, an essential part of the creative process (Torrance, 1993), it is recommended to pay closer attention to late ideas because there is "a greater proportion of good ideas among the later ideas on their lists" (Parnes, 1961, p. 121).

The dilemma is that, despite time as scarce organizational resource, if the longer the meeting the higher the chance of better solutions—groups and organizations would be even more tempted to keep generating ideas together in the hope of finding a game-changing solution. The challenge may be resolved if employees have generated ideas in advance during a noninteractive session, thus able to share quantity and quality ideas during early interaction. In hybrid brainstorming, members, during the preceding individual brainstorming session, should keep their ideas to themselves in the expectation to share them when they come together as a group (see Girotra et al., 2010; Korde & Paulus, 2017). As, first, solutions previously generated begin to "gush out" when interaction eventually starts, and second, fluency gradually attenuates (Kohn & Smith, 2011), more ideas will be produced early than late (Hypothesis 1a). Since *quantity* strongly correlates with *quality* (Nijstad et al., 2010) and *quantity* decreases over time, we expect that solution *quality*—*originality* (high on *originality*, 1b), *O-F* (high on *originality and feasibility*, 1c), *and O-U-F* (high on *originality, usefulness, and feasibility*, 1d)—*by count* (see Materials and Method) will display similar patterns. Additionally, *quantity* and *quality* measured by the number of quality solutions may plateau at some predictable time point, displaying a quadratic trend. This is because, first, mental association becomes increasingly difficult (see Figure 1 and Figure 3 in Kohn & Smith, 2011), and second, individuals would soon exhaust most of the individually (previously) generated solutions during early interaction.

A more interesting question might be about the “proportion” of *quality* solutions. On the one hand, later ideas may be scant but disproportionately more creative due to the spreading activation in semantic memory. If this effect is strong, it would provide a reason to persist in group brainstorming, despite decreasing idea *quantity* and *quality by count*. On the other hand, higher-quality ideas a person has generated may remain more salient in the person’s memory than lower-quality ideas. Since higher-quality ideas are more likely to meet personal needs or aspirations, the person would desire these ideas more strongly. The stronger the attitude towards an object (or an idea), the more cognitively accessible (i.e., salient) the attitude object (or an idea) becomes (Showers & Cantor, 1985). This could have individuals share first, when interaction starts, these better ideas cognitively more accessible to them (see Ward et al., 2002). Furthermore, group brainstorming following Osborn’s (1953) four rules provides a rare social opportunity, where members can be heard for their great ideas or solutions, because open criticism and interruption are explicitly forbidden (Sutton & Hargadon, 1996). However, although there is no explicit criticism, members still get lots of feedback. When sharing ideas, they will see the immediate facial expressions of the others. An idea may be treated as a joke, met with silence, or enthusiastic reaction (“Oh, I love that!”) Knowing they can be seen as brilliant, gain the respect of their peers, or in light of Festinger’s (1954) social comparison theory, affirm self-worth in comparison with others—members would want to mention first the ideas they deem more creative in order to appear competent. Sometime before sharing, there likely will be decisional processes (Simon, 1955) by members, voluntarily checking *quality* of their own ideas to decide which to share first. Thus, we hypothesize that a greater portion of higher-quality solutions will be mentioned first during early interaction (*originality*, Hypothesis 2a; *O-F*, 2b; and *O-U-F*, 2c)—all *by proportion*. If Hypothesis 2 is supported, it will imply that, contrary to the old suggestion, the early period is where to look first to decide which solutions to choose or develop if individual brainstorming preceded interaction.

### ***Diversity of Solutions***

*Diversity*, or the number of idea categories (Acar & Runco, 2017; Guilford, 1966), is distinct from other productivity metrics in that even a small or declining number of additional solution category may be impactful. According to spreading activation theory, once a particular node, which represents a concept, becomes active in working memory, activation spreads at a higher probability to nodes in semantic categories in memory that are strongly connected to the activated node (Collins & Loftus, 1975). In this sense, a new category is more than a new solution, because it could, akin to exposing participants to semantically heterogeneous solutions (Nijstad & Stroebe, 2006), cognitively stimulate during the following processes novel associations among distant conceptual nodes heretofore underexplored.

An idea a person generates becomes more strongly associated with the problem and search cues, increasing the chance that the next idea is semantically proximal to the previous one (idea fixation, Nijstad & Stroebe, 2006). Further, members during interaction would conform to (Smith et al., 1993) or build upon others' ideas, because group members tend to generate ideas that echo previously shared themes (Stasser & Titus, 1985). For these reasons, not only *diversity by count* (additional idea categories for each quarter; Hypothesis 3a), but also *diversity by proportion* (number of added solution categories divided by increased idea *quantity* for each quarter; 3b) will likely decrease.

Consequently, the number of added solution categories later in interaction might converge to a point at which, for solution *diversity*, it is not worth continuing to generate ideas, e.g., less than one additional solution category or additional-categories-to-*quantity* ratio of zero during fourth quarter of interaction. However, though participants are free to either persist in generating solutions in the same category or flexibly switch to another, they would particularly feel the urge to switch categories at moments the current category seems saturated that it is difficult to persist in it (Nijstad & Stroebe, 2006). Thus, it might be that the number of solution categories will be added in some meaningful proportion to additional solutions, retaining *diversity by count* reliably above 1 (3c) and additional-categories-to-solutions proportion (*diversity by proportion*) above zero (3d) until the end of interaction, as long as participants do generate any number of ideas by this time. To our knowledge, over-time changes of solution *diversity* have not been empirically tested, so the cutoffs proposed (above 1 *by count* and 0 *by proportion*) are for exploratory purposes given the lack of relevant prior literature.

### *Unconstrained vs. Constrained Norm*

Osborn (1953, p. 302) clarified that the “spirit of a brainstorm session” under the four traditional, noncritical rules is “encouragement” to feel safe to express any ideas that come to mind. Studies accordingly found that group brainstorming with the four noncritical rules produced more good solutions than a conventional meeting (McGrath, 1984), and that “psychological safety” to express themselves is positively associated with creative problem-solving capacity (Carmeli et al., 2014). Since those four rules create a safe climate for members to take risks to explore and share any possible mental combinations (Baer & Frese, 2003; Osborn, 1953), one could argue that the most effective norm for creative problem solving should be without any rule narrowing the scope of attention.

However, leading practitioners have added a unique emphasis, “Stay focused on topic” (Sutton & Hargadon, 1996), to the noncritical norm. Note that staying focused on task information will “restrict attention” (Sutton & Hargadon, 1996, p. 706). This cognitive constraint narrows the attention scope. First, it potentially deprives members of boundless options to free-associate concepts or share any thoughts. Second, it could damage psychological safety and trigger self-censorship of solutions that might not satisfy the task-related information one is aware of, either as judged by oneself or from fear of judgment by others (Baer & Frese, 2003). Subsequently, the group norm's emphasis on *unconstrained* brainstorming might lose its force.

Here, focused (System 2) and defocused attention (System 1) of the dual process theory (Kahneman, 2011) applied to recent creativity research may provide an insight. Due to the (associative) divergent thinking and (logical) convergent thinking styles that characterize generating options and decision making, respectively, researchers had conceptualized brainstorming as primarily defocused (System 1), rather than focused (System 2) in nature (Sowden et al., 2015). However, studies show both types of processing are actually co-present during effective brainstorming (Harvey & Kou, 2013; Nijstad et al., 2010; Sowden et al., 2015). Moreover, a certain balance between the focused and unfocused attention has been shown to lead to better creative problem solving than unqualified emphasis on free association (e.g., Haught-Tromp, 2017; Medeiros et al., 2014). One version of dual process model in creativity involves cognitive constraint that facilitates focused attention. Since human cognitive capacity is limited, having too many options, but no anchor, is cognitively overwhelming and "even paralyzing" (Haught-Tromp, 2017, p. 2), thus unfavorable for creative cognition in problem solving. This is an example of the *paradox of choice* (Schwartz, 2004). Similarly, Ward and Sifonis (1997) suggest that having a stable frame for imagination promotes generation of unusual ideas. Additionally, there was a finding that a norm to be critical—instead of noncritical—of others' ideas, which is another example of cognitively constraining norm, leads to the generation of better solutions (Levine et al., 2016, which we revisit in Discussion.)

Building on prior work, Study II examines for the first time whether a cognitive constraint, in the form of the newly introduced stay-focused rule, added to the traditional brainstorming norm improves solution generation. Although Putman and Paulus (2009) showed that a set of additional rules—to stay focused, to keep the brainstorming going, and to return to the previous categories—led to greater solution *quantity* as participants used given time more efficiently, the current study limits the focus on the *unconstrained*/*constrained* comparison by varying only the specific rule to stay focused. Note also that the utility of each of the long-accepted four rules (Osborn, 1953) and more recently added two ("One conversation at a time" and "Be visual"; Brown, 2009) has been studied and supported (see Carmeli et al., 2015 for review). Moreover, although hybrid brainstorming is the norm in real-world groups and organizations, the effects of cognitive constraints have been studied using only all-noninteractive and all-interactive brainstorming (e.g., Medeiros et al., 2014; Nemeth et al., 2004). For these reasons, we test the effect of adding the "Stay focused on topic" rule to the traditional *unconstrained* norm during noninteractive-then-interactive hybrid brainstorming. We predict higher performance (Hypothesis 4), in terms of *total quantity* of solutions during the entire brainstorming session (4a), *quality* (*originality*, 4b; *O-F*, 4c; *O-U-F*, 4d) *by count*, and *diversity* (the number of solution categories; 4e) for the *constrained* condition. As discussed, *quantity* (4a) and *quality by count* (4b to 4d) are expected to vary in the same pattern (Nijstad et al., 2010). *Diversity by count* (4e) will likewise vary in the same direction as *quantity*, because with more generated solutions, more of these solutions would represent diverse categories (Levine et al., 2016).

***Constraint Effect over Time***

Combining the reversed serial-order effect and the cognitive constraint effect, we hypothesize the *quantity* difference between *constrained* and *unconstrained* conditions during interaction will be significant only early—first quarter of interaction—rather than later (Hypothesis 5a). Since creative momentum tends to quickly diminish even within brief, fixed time frames (e.g., 2-4 minutes; Kohn & Smith, 2011), the between-group difference would disappear as participants in both conditions lose steam over time. As a corollary to the above predictions, we expect that *quality*—*originality* (5b), *O-F* (5c), and *O-U-F* (5d)—*by count* during early (the first quarter of) interaction will likewise be greater for the *constrained*, though the differences will quickly disappear over time. Hypothesis 5, if supported, will imply that higher productivity during early interaction can be further enhanced by the *constraint*.

Additionally, we test if the gains due to cognitive constraint, if any, are from its effect on either the preceding noninteractive session or interactive session, or both. To be consistent with a constraint enhancing performance during both individual brainstorming (e.g., Medeiros et al., 2014), as well as with interactive brainstorming (e.g., Levine et al., 2016; Nemeth et al., 2004), we hypothesize a mediation (an indirect) effect of *quantity from individual session* on *quantity from interactive session* (Hypothesis 6a), and a direct effect of cognitive constraint on *quantity from interactive session* (6b).

Finally, answering the call for more research on creative decision making (Girotra et al., 2010), we explore between-condition differences in the *O-F* (Research Question 1) and *O-U-F* (Research Question 2) (all *by count*) of solutions decided upon by groups as their best top three solutions.

## Materials and Methods

### Participants and Design

There were 231 undergraduate students at a large, Midwestern university in the United States. They received extra credit in a communication class. We randomly assigned participants to *unconstrained* (41 groups, $n$ = 123) or *constrained* condition (36 groups, $n$ = 108)[7]. All groups were video-recorded on a server. The server reached its memory quota without experimenter's knowledge, so the server automatically deleted 22 recordings as it saved new data. A one-sample clustered power analysis for the temporal change in creative performance revealed that the reduced sample size of N = 165 (55 three-person groups; 28 *unconstrained* and 27 *constrained*) was still sufficient to detect a small to medium effect size ($d$ = .38) with 80% power (two-tailed). For testing the mean performance differences between the two conditions with N = 165 (55 three-person groups), we conducted two types of power analysis (1) one without considering the nested data structure and (2) one using clustered randomized design. The first power analysis revealed that N = 165 was sufficient to detect a medium effect size ($d$ = .6) with 95% power (two-tailed). On the other hand, the second test showed that the 55 three-person groups were also sufficient to detect a medium effect size ($d$ = .6), but with 61% power (two-tailed). We compared two conditions (Hypotheses 3 and 4, Research Questions 1 and 2) using multilevel linear modeling, and performed a mediation analysis on the relationship between condition and *quantity from interactive session* through *quantity from individual session* (Hypothesis 6) using 77 groups (41 *unconstrained*; 36 *constrained*), but analyses of temporal performance changes averaged across conditions (Hypotheses 1-3) and between-condition differences over time (Hypothesis 5) had 55 groups (28 *unconstrained*; 27 *constrained*).

Mindful of ecological validity (Paulus et al., 2015), we had participants generate solutions for an industrial application. We also emulated the current face-to-face brainstorming

[7] This study constituted one-half of a larger laboratory session that involved two studies. The two studies look at different parts of the data from one session and make comparative analyses that do not overlap.

practices by using trained facilitators and semiotic resources such as a whiteboard, post-it notes, and markers (Brown, 2009).

### ***Procedure***

Participants completed consent forms and were randomly assigned to condition. Seated at a table in front of a whiteboard, each person received a sheet on rules, post-it notes of a certain color different from other members', and a marker. The facilitator[8] told participants in both conditions that they will generate ideas together and showed them a two-minute video tutorial of brainstorming (Cheung, 2017). Then participants were told to generate as many creative solutions as they could.

Participants read aloud either one of two versions of the rule sheet (*unconstrained* or *constrained*). Then the facilitator explained the rules. The only difference between the *unconstrained* and *constrained* condition was the absence or presence of the stay-focused rule that we introduced before the other rules. The introduction for the *constrained* condition began, "'Stay focused on the topic' is above all the most important rule! Do not veer off from the problem information at hand." The facilitator emphatically communicated the stay-focused rule to create an attention to the relevant information. Then, explanation of the six rules from "Defer judgment" followed. By contrast, the *unconstrained* condition had only six rules that started from "Defer judgment." After introducing the norm, participants in each condition were asked to briefly summarize verbally how they understood the rules. After checking that all participants

[8] There were seven trained facilitators: six undergraduate research assistants and the first author, who facilitated six (four *constrained* and two *unconstrained*; 6/77 = 7.8.% of total) groups only when the research assistants were unavailable. The pattern of statistical significance for all findings in this study was the same without the six groups facilitated by the first author, except for only Hypothesis 4d (between-condition difference in *O-U-F by count*), which changed from significant ($p$ = .04) to nonsignificant ($p$ = .13). However, this does not seem to affect the implications of this study. Each facilitator alternated between the two conditions. They trained prior to the experiment by facilitating several pilot sessions. While leading, they had a guideline packet in hand about enforcing the rules, so that the level and style of facilitation could be largely equivalent.

completely understood their given norm (either *unconstrained* or *constrained*), the facilitator introduced the task. The rule sheets for each condition stayed on the table the entire session for participants to keep reminded of their given norm.

**Task**. The facilitator presented the practice task: "Prepare an unforgettable gift-receiving experience for someone close to you with only $10!" For one minute, they individually filled out post-it notes, one for each solution. Then as a group, they freely shared ideas while still generating ideas for the next minute. To share an idea, a member briefly explained it while passing the post-it note to the facilitator, who immediately put it on the whiteboard for everyone to see. The facilitator reminded participants not to forget to keep generating ideas while listening to others during interaction. Next, the facilitator presented the main problem:

> Create the most awesome backpack in the world for college students like you! You are part of a product development team in a huge sportswear company. The sales are down by 50%! The future of your company depends on your creative solutions!

The facilitator clearly articulated this problem statement, so that participants could take advantage of the information, for example, by staying focused on its details so as not to miss the target (ordinary college students). We selected this topic (backpack) based on pilot-testing and after considering a proper difficulty level for the undergraduates. Participants generated solutions individually first for 6 minutes, then, together for 12 minutes[9]. When time was up, we asked participants to individually decide upon three solutions, so that conformity would be reduced. Then we asked them to discuss as a group to decide upon their top three solutions.

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[9] Kohn and Smith (2011) showed idea generation slows down considerably within 5 minutes. Further, Levine et al. (2016) reported an average of 14 to 17 minutes of interactive brainstorming. We set the times (6 and 12 minutes) (1) reflecting these studies, (2) after pilot-testing, and (3) adopting the same 1:2 ratio from Girotra et al. (2010), who used 10-minute individual brainstorming followed by 20-minute interactive brainstorming.

**Measures**. To test how performance (*quantity* and *quality*) changed across four measurement points (Hypotheses 1 and 2), we used a multilevel model with solution *quantity*, *quality* (*originality*, *O-F, and O-U-F*), or *diversity* of non-selected solutions as level-1 outcome variables, random intercept varying by individual ID within group by facilitator, all with correlated error variances to account for non-independence among members. Measurement points were nested within individuals within groups, with facilitators guiding multiple groups. We selected contrasts to test for linear and quadratic patterns in outcome variables as well as a difference between them at the first and last quarters. We fit models with the following equation:

$$Outcome_{ijkl} = r_{0000} + r_{1000}Time_i + u_{0jkl} + e_{ijkl},$$

where $i$ = measurement occasion, $j$ = individual, $k$ = group, and $l$ = facilitator. For Hypothesis 3a (*diversity by count*) and 3b (*diversity by proportion*),

$$Outcome_{ijk} = r_{000} + r_{100}Time_i + u_{0jk} + e_{ijk},$$

where $i$ = measurement occasion, $j$ = group, and $k$ = facilitator. To test for significant addition of *diversity* towards late interaction, we used an equivalence test (3c) and a one-sample $t$-test (3d). For Hypotheses 4 (between-condition comparison of performance) and 5 (condition-by-time comparison), we used multilevel modeling with the condition (*unconstrained* or *constrained*) as the level-2 predictor,

$$Outcome_{ijk} = r_{000} + r_{010}Condition_j + u_{0jk} + e_{ijk},$$

where $i$ = individual, $j$ = group, and $k$ = facilitator. We performed the mediation analysis (Hypothesis 6) using multilevel structural equation modeling given the nested data structures. We modeled the effects of interest simultaneously at both individual and group levels of analysis (see Figure 6).

**Performance.** ***Quantity.*** We took number of non-selected ideas as *quantity* of solutions for each respective segment (*quantity from individual session* and *quantity from interactive session*) or the entire hybrid session (*total quantity*). We counted solutions by reviewing videos recorded from two angles and by the number of post-it notes (one per idea) produced by each participant. ***Quality and Diversity by Count and Proportion***. We measured *originality, feasibility,* and *usefulness* by number of solutions rated "good" by independent coders on each criterion, respectively. We calculated the number of solutions "good" on more than one criterion as *O-F* and *O-U-F* (explained below). We assigned a category to each solution based on a pre-formulated coding scheme (see below). We divided measures *by count* by solution *quantity* in each time quarter during interaction to calculate *quality* or *diversity by proportion*. ***Coding Scheme.*** Following the consensual assessment technique (CAT) by Amabile (1982), trained coders content-analyzed a total of 3,570 solutions (excluding selected solutions) generated by the participants. On a 1 (*very bad*) to 4 (*very good*) scale, raters scored each solution on *originality*, *feasibility*, and *usefulness* (Rietzschel et al., 2010). A practicing industrial designer with backpack design experience participated in developing our codebook (see Amabile, 1982). Three independent raters, blind to condition, coded *originality* and *feasibility* of solutions, while other three blind raters coded *usefulness*. Adopting Parnes' (1961) method, solutions given the score of 3 or 4 were "good" and 1 or 2 "bad" on each criterion. KALPHA in the first round involving 250 solutions did not meet inter-coder reliability on *originality* (.591), *feasibility* (.679), or *usefulness* (.668). After more training, the next round with another 250 solutions had a KALPHA 830, .863, and .909, respectively. Each coder coded a portion of the remaining solutions. Only solutions "good" on both *originality* and *feasibility* counted towards *O-F*, and all three "good" on *originality, usefulness,* and *feasibility* towards *O-U-F* (see Rietzschel et al., 2010). For *diversity*, three independent raters, blind to condition, first coded each of 250 solutions into one of 21 semantic categories using a coding scheme based on their conceptual closeness (Nijstad et al., 2010). Examples are “hygiene” (e.g., hand sanitizer dispenser), “weather” (e.g., pop-up hood attached), and “safety” (e.g., panic button). Thus, we measured *diversity by count* by the number of categories (Guilford, 1966) rather than by the number of category shifts (see Acar & Runco, 2017; Torrance, 1974). The first round did not meet inter-coder reliability (KALPHA: .669). The following round with another 250 ideas resulted in KALPHA .933. Then they coded a portion of the remaining solutions.

**Table 7**

*Descriptive statistics of outcome variables for each participant*

| Variable | Aggregated (n = 165, 55 groups) | | Unconstrained (n = 84, 28 groups) | | Constrained (n = 81, 27 groups) | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Over-time changes | | | | | | |
| Quantity | | | | | | |
| 1QR | 5.89 | 3.21 | | | | |
| 2QR | 4.47 | 2.16 | | | | |
| 3QR | 2.65 | 1.86 | | | | |
| 4QR | 2.14 | 1.87 | | | | |
| Originality (Count) | | | | | | |
| 1QR | 3.52 | 2.14 | | | | |
| 2QR | 2.38 | 1.52 | | | | |
| 3QR | 1.37 | 1.31 | | | | |
| 4QR | 0.95 | 1.12 | | | | |
| O-F (Count) | | | | | | |
| 1QR | 2.93 | 1.96 | | | | |
| 2QR | 1.88 | 1.47 | | | | |
| 3QR | 1.08 | 1.14 | | | | |
| 4QR | 0.71 | 0.96 | | | | |
| O-U-F (Count) | | | | | | |
| 1QR | 2.11 | 1.63 | | | | |
| 2QR | 1.28 | 1.10 | | | | |
| 3QR | 0.65 | 0.88 | | | | |
| 4QR | 0.42 | 0.71 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Originality (Proportion) | | | | | | |
| 1QR | .60 | .26 | | | | |
| 2QR | .54 | .28 | | | | |
| 3QR | .51 | .35 | | | | |
| 4QR | .46 | .37 | | | | |
| O-F (Proportion) | | | | | | |
| 1QR | .50 | .25 | | | | |
| 2QR | .42 | .29 | | | | |
| 3QR | .41 | .34 | | | | |
| 4QR | .35 | .37 | | | | |
| O-U-F (Proportion) | | | | | | |
| 1QR | .35 | .23 | | | | |
| 2QR | .29 | .24 | | | | |
| 3QR | .26 | .29 | | | | |
| 4QR | .24 | .32 | | | | |
| Diversity (Count) | | | | | | |
| 1QR | 10.62 | 2.56 | | | | |
| 2QR | 2.65 | 1.49 | | | | |
| 3QR | 0.96 | 1.05 | | | | |
| 4QR | 1.10 | 1.11 | | | | |
| Diversity (Proportion) | | | | | | |
| 1QR | .69 | .25 | | | | |
| 2QR | .20 | .11 | | | | |
| 3QR | .11 | .14 | | | | |
| 4QR | .15 | .17 | | | | |
| Between-condition (count) | | | | | | |
| Generation | | | | | | |
| Originality | | | 8.07 | 3.46 | 10.15 | 3.98 |
| O-F | | | 6.60 | 3.24 | 8.30 | 3.93 |
| O-U-F | | | 4.38 | 2.37 | 5.10 | 2.68 |
| Diversity | | | 9.18 | 2.36 | 10.49 | 2.28 |
| Decision Making | | | | | | |
| O-F | | | 1.73 | 0.08 | 1.58 | 0.84 |
| O-U-F | | | 0.07 | 0.26 | 0.03 | 0.17 |

*Note.* O-F: originality *and* feasibility. O-U-F: originality, usefulness, *and* feasibility (see Rietzschel et al., 2010).

# Results

## Over-Time Performance by Count

Averaged across conditions, performance—*quantity* (Hypothesis 1a) and *quality* (*originality* [1b], *O-F* [1c], and *O-U-F* [1d]) *by count*—was higher during early interaction and decreased over time, exhibiting linear and quadratic trends. (Please see the OSF repository for the data[10] for complete statistical results.) All subhypotheses of Hypothesis 1 received support at $p < .01$.

**Table 8**

*Performance (quantity and quality [originality, O-F, and O-U-F] by count) during the 1st over the 4th quarter for each participant (Hypotheses 1a to 1d)*

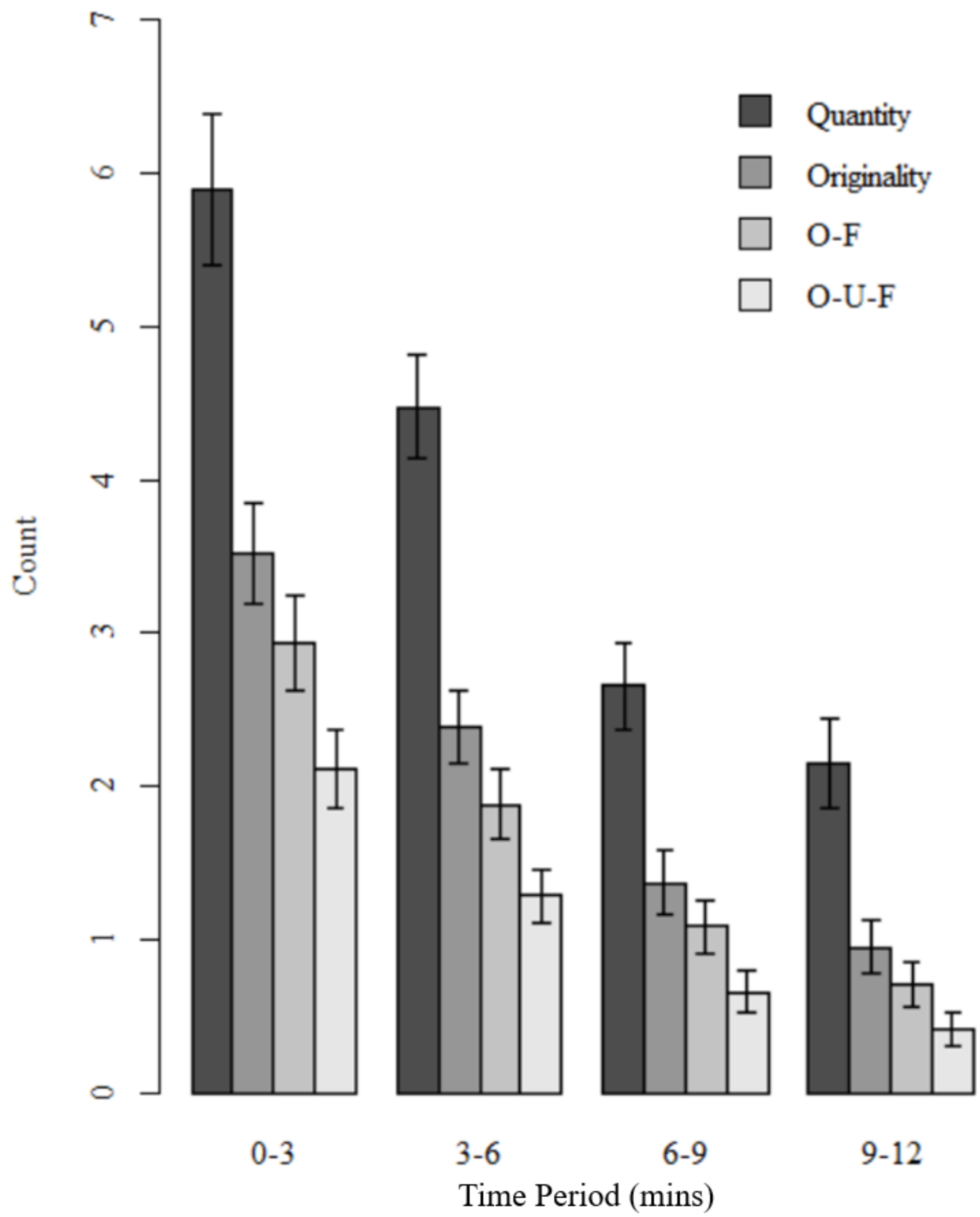
| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| Quantity (1a) | | | | | | |
| Intercept ($\gamma_{0000}$) | 3.81 | | | | | |
| Time ($\gamma_{1000}$) | 4.25 | 0.56 | 8.00 | 159.02 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 0.02 |
| Within-group variances ($\sigma^2$) | | | | | | 5.96 |
| Originality (Count) (1b) | | | | | | |
| Intercept ($\gamma_{0000}$) | 2.06 | | | | | |
| Time ($\gamma_{1000}$) | 3.03 | 0.36 | 8.48 | 159.02 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 0.09 |
| Within-group variances ($\sigma^2$) | | | | | | 2.55 |
| O-F (Count) (1c) | | | | | | |
| Intercept ($\gamma_{0000}$) | 1.61 | | | | | |
| Time ($\gamma_{1000}$) | 2.56 | 0.31 | 8.15 | 159.02 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 0.01 |
| Within-group variances ($\sigma^2$) | | | | | | 2.51 |
| O-U-F (Count) (1d) | | | | | | |
| Intercept ($\gamma_{0000}$) | 1.08 | | | | | |
| Time ($\gamma_{1000}$) | 1.71 | 0.24 | 7.00 | 161.02 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 0.04 |
| Within-group variances ($\sigma^2$) | | | | | | 1.51 |

*Note.* ** $p < .01$. O-F: originality *and* feasibility. O-U-F: originality, usefulness, *and* feasibility (see Rietzschel et al., 2010).

[10] https://osf.io/9yujk/?view_only=e463f7cb57454bca96b9c3ee06e03e57

**Figure 2**

*Performance by count over time (means and standard errors) of a group member during interactive brainstorming preceded by individual brainstorming (Hypothesis 1)*




**Over-Time Performance by Proportion**

Averaged across conditions, we hypothesized that *quality*—*originality* (Hypothesis 2a), *O-F* (2b), and *O-U-F* (2c)—*by proportion* will be higher during early interaction and decrease over time in linear and quadratic patterns. All subhypotheses of Hypothesis 2 for the linearly declining patterns received support at $p < .01$. However, there were no significant quadratic trends. Thus, Hypothesis 2 received partial support.

**Table 9**

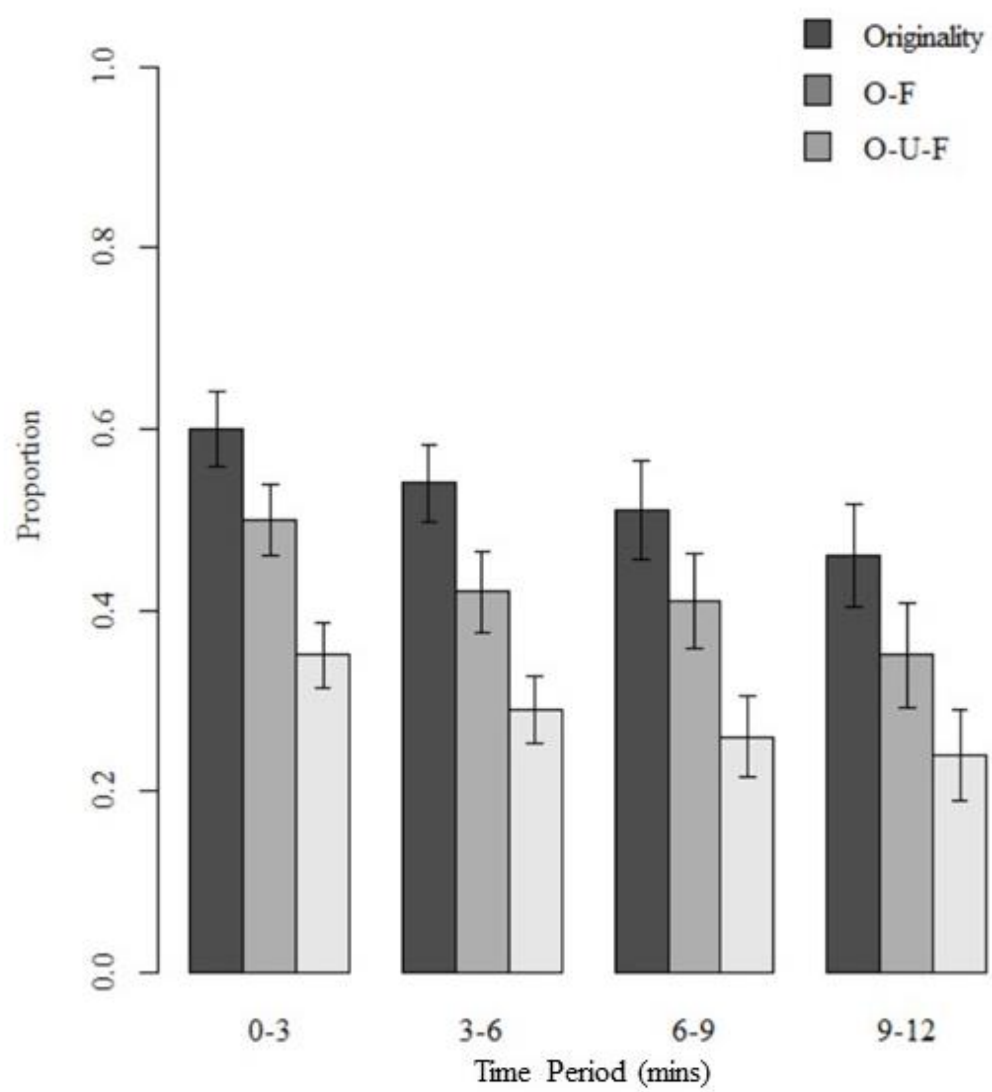
*Quality (originality, O-F, and O-U-F) by proportion during the 1st over the 4th quarter for each participant (Hypotheses 2a to 2c)*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| Originality (Proportion) (2a) | | | | | | |
| Intercept ($\gamma_{0000}$) | .51 | | | | | |
| Time ($\gamma_{1000}$) | .19 | .07 | 2.64 | 137.03 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | .01 |
| Within-group variances ($\sigma^2$) | | | | | | .13 |
| O-F (Proportion) (2b) | | | | | | |
| Intercept ($\gamma_{0000}$) | .40 | | | | | |
| Time ($\gamma_{1000}$) | .20 | .07 | 2.72 | 137.03 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | < .01 |
| Within-group variances ($\sigma^2$) | | | | | | .14 |
| O-U-F (Proportion) (2c) | | | | | | |
| Intercept ($\gamma_{0000}$) | .27 | | | | | |
| Time ($\gamma_{1000}$) | .17 | .06 | 2.78 | 137.03 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | < .01 |
| Within-group variances ($\sigma^2$) | | | | | | .13 |

*Note*. ** $p < .01$. O-F: originality *and* feasibility. O-U-F: originality, usefulness, *and* feasibility (see Rietzschel et al., 2010).

**Figure 3**

*Performance by proportion over time (means and standard errors) of a group member during interactive brainstorming preceded by individual brainstorming (Hypothesis 2)*




We found no other polynomial relationship in any of the above analyses.

**Diversity**

We hypothesized that *diversity by count* (Hypothesis 3a) and *by proportion* (3b), averaged across conditions, would be higher during early interaction and decrease over time, exhibiting linear and quadratic trends. Both received partial support given their steeply linear (*p*

< .01) but non-quadratic declining patterns. In addition, that *diversity by count* during late interaction will be greater than 1 (3c) and *diversity by proportion* greater than zero (3d) received support at $p = .87$ and $p < .01$, respectively.

**Table 10A**

*Solution diversity increase by count and proportion during the 1st over the 4th quarter for each participant (Hypotheses 3a and 3b)*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| 1QR Diversity by Count (3a) | | | | | | |
| Intercept ($\gamma_{000}$) | 3.49 | | | | | |
| Constraint ($\gamma_{100}$) | 9.64 | 1.11 | 8.71 | 40.13 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | < .01 |
| Within-group variances ($\sigma^2$) | | | | | | 20.64 |
| 1QR Diversity by Proportion (3b) | | | | | | |
| Intercept ($\gamma_{000}$) | 0.28 | | | | | |
| Constraint ($\gamma_{100}$) | 0.68 | 0.12 | 5.83 | 40.13 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | < .01 |
| Within-group variances ($\sigma^2$) | | | | | | 0.10 |

*Note.* ** $p < .01$

**Table 10B**

*Retained momentum for diversity by count and proportion (Hypotheses 3a and 3d)*

| Outcome Variable | Mean | Range [ ] / 95% CI ( ) | *Df* | *t* | *p* |
|---|---|---|---|---|---|
| (Equivalence Test) | | | | | |
| Diversity by Count | 1.18 | [0, 1] | 54 | 1.15 | .87 |
| (One-Sample *t*-Test) | | | | | |
| Diversity by Proportion | .18 | (.13, .23) | 54 | 7.14 | < .01** |

*Note.* The equivalence test examined whether *diversity* by count in the final measurement occasion was reliably outside of the range (0, 1). The diversity by count was reliably outside this range, $t(54) = 1.15$, $p = .87$.
** $p < .01$

**Figure 4**

*Added solution diversity (category) by count over time (means and standard errors) of a three-person group during interactive brainstorming preceded by individual brainstorming (Hypothesis 3a)*

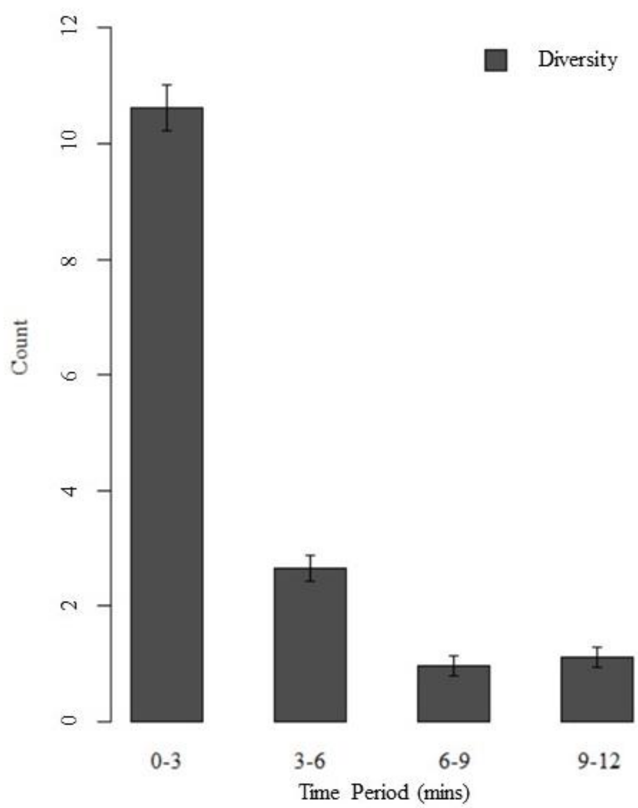
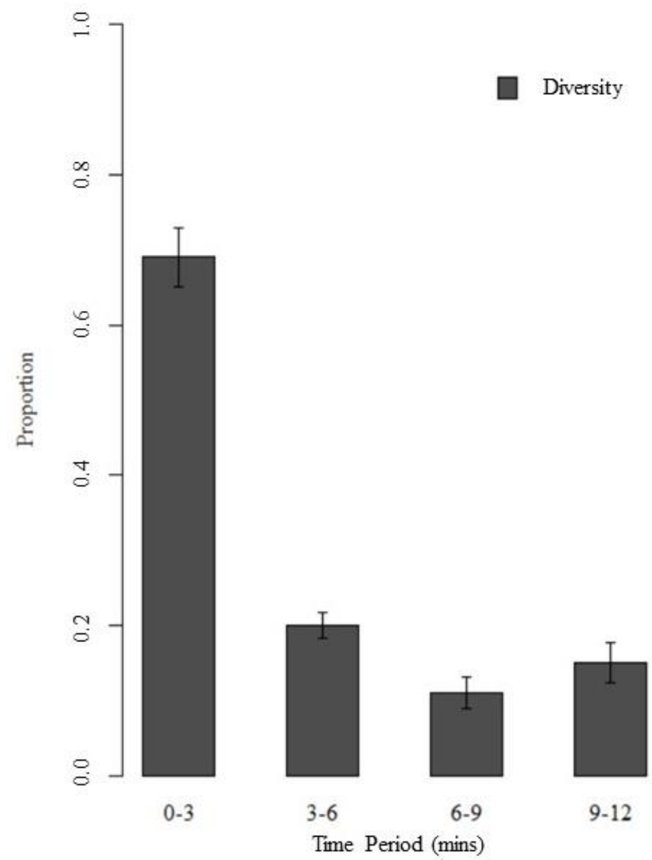


**Figure 5**

*Added solution diversity (category) by proportion over time (means and standard errors) as a three-person group during interactive brainstorming preceded by individual brainstorming (Hypothesis 3b)*




## Constraint Effect

*Total quantity* (Hypothesis 4a), *quality* (*originality* [4b], *O-F* [4c], and *O-U-F* [4d]) *by count*, and *diversity by count* (4e) were greater for the *constrained* than *unconstrained* condition. Hypotheses 4a, 4b, 4c, and 4e received support at $p < .01$ and 4d at $p = .04$; Hypothesis 4 received support.

**Table 11**
*The constraint (level-2 predictor) effect on total quantity, quality (originality, O-F, and O-U-F) by count, and diversity by count for each participant (Hypotheses 4a to 4e)*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| Total Quantity (4a) | | | | | | |
| Intercept ($\gamma_{000}$) | 14.25 | | | | | |
| Constraint ($\gamma_{010}$) | 2.79 | 0.89 | 3.14 | 70.31 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 12.93 |
| Within-group variances ($\sigma^2$) | | | | | | 22.69 |
| Originality (Count) (4b) | | | | | | |
| Intercept ($\gamma_{000}$) | 7.65 | | | | | |
| Constraint ($\gamma_{010}$) | 2.17 | 0.48 | 4.53 | 70.09 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 1.83 |
| Within-group variances ($\sigma^2$) | | | | | | 12.20 |
| O-F (Count) (4c) | | | | | | |
| Intercept ($\gamma_{000}$) | 6.13 | | | | | |
| Constraint ($\gamma_{010}$) | 1.81 | 0.46 | 3.92 | 70.39 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 1.90 |
| Within-group variances ($\sigma^2$) | | | | | | 11.11 |
| O-U-F (Count) (4d) | | | | | | |
| Intercept ($\gamma_{000}$) | 4.29 | | | | | |
| Constraint ($\gamma_{010}$) | 0.76 | 0.36 | 2.09 | 72.64 | .04* | |
| Between-group variances ($\tau^2$) | | | | | | 0.87 |
| Within-group variances ($\sigma^2$) | | | | | | 5.54 |
| Diversity (4e) | | | | | | |
| Intercept ($\gamma_{000}$) | 8.99 | | | | | |
| Constraint ($\gamma_{010}$) | 1.35 | 0.34 | 4.00 | 70.48 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 1.45 |
| Within-group variances ($\sigma^2$) | | | | | | 4.05 |

*Note*. * $p < .05$; ** $p < .01$. O-F: originality *and* feasibility. O-U-F: originality, usefulness, *and* feasibility (see Rietzschel et al., 2010).

## Constraint Effect over Time

We compared effects of *constrained* and *unconstrained* on *quantity* (Hypothesis 5a) and *quality* (*originality* [5b], *O-F* [5c], *and O-U-F* [5d]) *by count* within the first quarter, to test if cognitive constraint positively affects performance during early interaction. All subhypotheses of Hypothesis 5 received support at $p < .01$. Though not hypothesized, we tested for the second, third, and fourth quarters using the same measures and found no difference between conditions. These non-significant findings are consistent with our results for Hypothesis 1 as productivity quickly declines within the first few minutes of interaction.

**Table 12**

*The constraint (level-2 predictor) effect on quantity and quality (originality, O-F, and O-U-F) by count during the 1s quarter for each participant (Hypotheses 5a to 5d)*

| Outcome Variable | Fixed Effect | | | | | Random Effect |
|---|---|---|---|---|---|---|
| | Coefficient | SE | *t*-ratio | *df* | *p*-value | SD |
| 1QR Quantity (5a) | | | | | | |
| Intercept ($\gamma_{000}$) | 4.46 | | | | | |
| Constraint ($\gamma_{010}$) | 2.42 | 0.67 | 3.63 | 49.58 | < . 01** | |
| Between-group variances ($\tau^2$) | | | | | | 5.39 |
| Within-group variances ($\sigma^2$) | | | | | | 3.90 |
| 1QR Originality (Count) (5b) | | | | | | |
| Intercept ($\gamma_{000}$) | 4.12 | | | | | |
| Constraint ($\gamma_{010}$) | 1.55 | 0.37 | 4.21 | 47.85 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 0.94 |
| Within-group variances ($\sigma^2$) | | | | | | 3.32 |
| 1QR O-F (Count) (5c) | | | | | | |
| Intercept ($\gamma_{000}$) | 1.73 | | | | | |
| Constraint ($\gamma_{010}$) | 0.69 | 0.24 | 2.84 | 48.57 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 0.26 |
| Within-group variances ($\sigma^2$) | | | | | | 1.80 |
| 1QR O-U-F (Count) (5d) | | | | | | |
| Intercept ($\gamma_{000}$) | 1.53 | | | | | |
| Constraint ($\gamma_{010}$) | 0.96 | 0.28 | 3.43 | 47.60 | < .01** | |
| Between-group variances ($\tau^2$) | | | | | | 0.61 |
| Within-group variances ($\sigma^2$) | | | | | | 1.92 |

*Note*. ** $p < .01$ O-F: originality *and* feasibility. O-U-F: originality, usefulness, *and* feasibility (see Rietzschel et al., 2010).

## Mediation between Constraint and Quantity from Interactive Session

There was no significant indirect effect of constraint on *quantity from interactive session* through *quantity from individual session* (Hypothesis 6a), $p = .80$. We found no direct constraint effect on *quantity from interactive session* (6b), $p = .28$. The total effect of constraint on *quantity from interactive session* was also nonsignificant, $p = .29$. Observed mediation was inconsistent with Hypothesis 6.

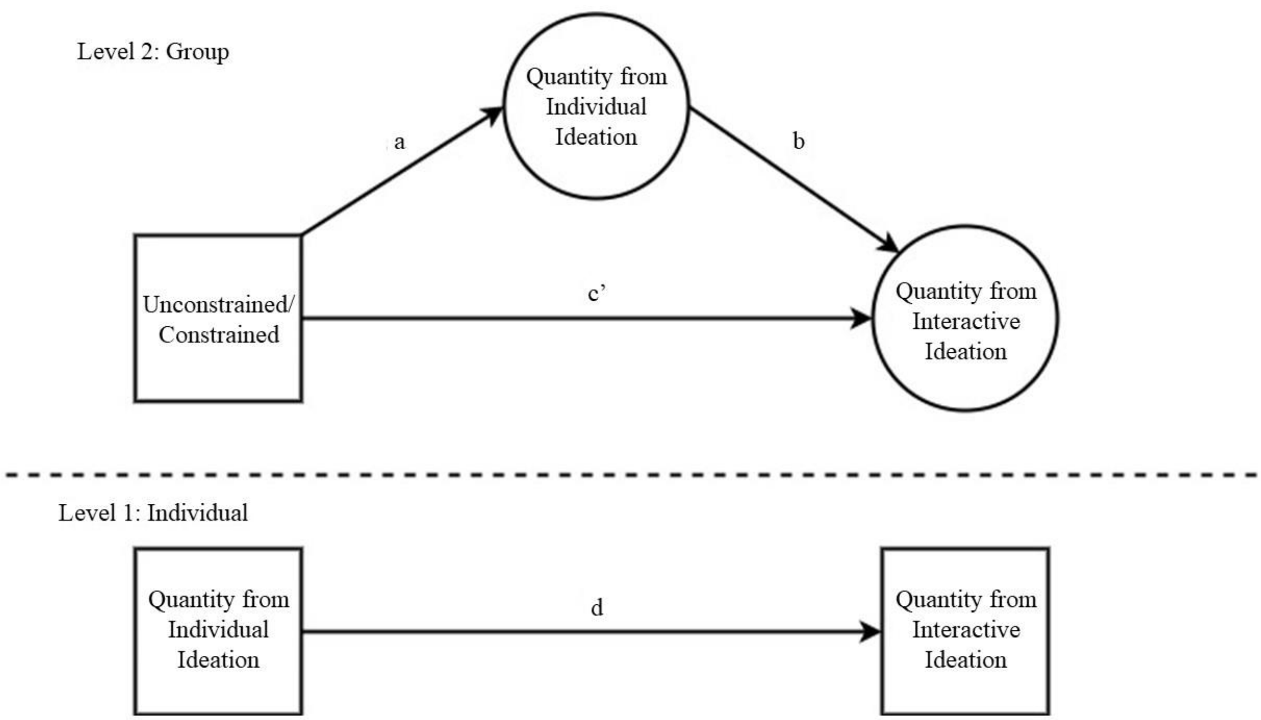
**Table 13**

*Mediation between condition and quantity from interactive session through quantity from individual session (Hypotheses 6a and 6b)*

| Total effect (*c*) | | Direct effect (*c'*) | | Indirect effect (*ab*) | | |
|---|---|---|---|---|---|---|
| Coefficient | *p*-value | Coefficient | *p*-value | Coefficient | *p*-value | Proportion mediated |
| .14 | .29 | .15 | .28 | -.01 | .80 | -.08 |

**Figure 6**

*Multilevel mediation model testing the constraint effect on quantity from interactive session mediated by quantity from individual session (Hypothesis 6)*




*Note.* For path coefficients of this model, please see Table 13, which accounts for the nested data structure.

**Quality of Solutions Decided on**

*O-F and O-U-F by count* (Research Questions 1 and 2) of the three solutions decided upon by groups were not higher for *constrained* than *unconstrained* groups ($p$ = .20 and $p$ = .46, respectively.)

**Table 14**

*The constraint effect on O-F (Research Question 1) and O-U-F (Research Question 2) by count among the solutions decided on.*

| Independent variable | Intercept | Estimate | *SE* | *t* | *p* |
|---|---|---|---|---|---|
| Constraint | | | | | |
| O-F | 1.61 | < .01 | < 0.01 | -1.29 | .20 |
| O-U-F | 0.06 | 0.00 | < 0.01 | 0.75 | .46 |

*Note.* O-F: originality *and* feasibility. O-U-F: originality, usefulness, *and* feasibility (see Rietzschel et al., 2010). For *O-F* and *O-U-F* of solutions decided on, we aggregated selected solutions at the group level and there was no issue of non-independence.

## Discussion

**Reversed Serial-Order Effect**

Using the ecologically valid (Girotra et al., 2010; Korde & Paulus, 2017) yet understudied individual-interactive hybrid paradigm, we tested whether solution *quality* increases over time (see Figure 1), which had been repeatedly found in previous studies using either the all-individual or all-interactive paradigm (e.g., Baruah & Paulus, 2016; Beaty & Silvia, 2012; Christensen et al., 1957; Johns et al., 2001; Johnson & D'Lauro, 2018; Milgram & Rabkin, 1980; Parnes, 1961; Phillips & Torrance, 1977; Runco, 1986; Ward, 1969). A conventional application of the serial-order effect, based on spreading activation, would predict that more feasible (or common) ideas will be generated first and more novel ideas later. The suggestions, thus, have been that—despite the important fact that time is a scarce organizational resource (Acar et al., 2019; Amabile & Pratt, 2016; Andrews & Smith, 1996)—we decide to endure through a lengthy group session (e.g., Christensen et al., 1957; Johnson & D’Lauro, 2018; Ward, 1969) and look to alternatives produced later to find better solutions (e.g., Parnes, 1961). When the group session began after an individual session, however, all our indicators of performance—*quantity* (Hypothesis 1a) and *quality*—*originality* (1b), *O-F* (1c), and *O-U-F* (1d)—*by count* peaked early and then gradually decayed, exhibiting linear and quadratic patterns over time. Interestingly, we observed a parallel pattern for *originality* (2a), *O-F* (2b), and *O-U-F* (2c) *by proportion*, which commonly showed a linear (though not quadratic) decline. This "reversed" serial-order effect suggests that, if sufficient time to generate ideas in solitude precedes the group session, it may not be necessary to generate ideas in a lengthy meeting even if the goal were to obtain high-quality solutions. Second, we may need to decide to first look into early solutions generated during interaction, rather than searching for best solutions from late ideas (see Parnes, 1961).

As discussed in Hypotheses, from a cognitive perspective, individually generated high-quality solutions would remain more salient in memory than worse solutions, so participants would share the better ones first when interaction starts. From a social perspective, individuals during group brainstorming would engage in impression management.

Given the distinctive value of solution *diversity* (see Acar & Runco, 2017; Guilford, 1966; Nijstad et al., 2010), we separately tested if *diversity by count* (Hypothesis 3a) or *proportion* (3b) decreases over time during the interaction. Both declined sharply during early interaction. Further, participants maintained their momentum for *diversity*—both *by count* (3c) and *by proportion* (3d), despite their steeply declining patterns—until the end of the group session. These results (3c/d) add nuance to our discussion on extended group brainstorming following individual brainstorming that, if the goal were to increase solution *diversity*, we may decide to persist in group brainstorming, despite solution *quantity* and *quality* decreasing over time (Hypotheses 1 and 2). The spreading of activation from close to distant concepts in the long-term memory seems to account for it (see Hypotheses).

**Cognitive Constraint Effect**

A cognitive constraint that narrowly focuses the scope of attention (System 2), which was an apparent mismatch with the unqualified emphasis on *unconstrained*, defocused attention (System 1), has recently been found to stimulate creative problem solving for both individual and group settings (Levine et al., 2016; Medeiros et al., 2014). We tested the effect of a cognitively constraining norm, which is widely accepted in the industry (Brown, 2009; Sutton & Hargadon, 1996), on individual-to-interactive hybrid brainstorming. Groups with the updated, cognitively *constraining* norm achieved higher *total quantity* from the entire hybrid session (Hypothesis 4a), *quality—originality* (4b), *O-F* (4c), and *O-U-F* (4d)—*by count* and *diversity by count* (4e), in comparison to groups with the traditional, *unconstraining* norm. We found that higher productivity during early interaction can be further enhanced by the *constrained* condition (Hypothesis 5). Within our multilevel mediation model for the individual-then-interactive brainstorming paradigm, *quantity from individual session* did not mediate the effect of constraint on *quantity from interactive session* (Hypothesis 6a), and constraint had no direct effect on *quantity from interactive session* (6b), either. Yet, in post hoc analyses, we found a trend of the positive effect of cognitive constraint, separately, on *quantity from individual session* ($p$ = .096) and on *quantity from interactive session* ($p$ = .087).

The results from Hypotheses 4 and 5 reveal a positive effect of cognitive constraint on individual-interactive hybrid brainstorming, particularly during early interaction. Post hoc tests for Hypothesis 6 show a trend towards significance of constraint on individual brainstorming and interactive brainstorming, separately. This demonstrates the utility of the updated, *constrained* norm for brainstorming as well as extends the findings of earlier studies—that *constrained*, rather than *unconstrained*, scope of attention has positive effects on creativity (Haught-Tromp, 2017; Medeiros et al., 2014; Levine et al., 2016)—to the more generalizable individual-group hybrid brainstorming. These findings add to the growing evidence that conceptual association and expression of opinions that are unconventional do not seem to be reached most effectively by a completely *unconstrained* cognition (e.g., Harvey & Kou, 2013; Haught-Tromp, 2017; Medeiros et al., 2014; Nemeth et al., 2004). First, from a cognitive perspective, a constraint can act as a cognitive anchor which helps avoid being lost in the unlimited, thus overwhelming, possibilities. The rule to stay focused could have provided helpful cognitive anchors. A second explanation is that because a cognitive constraint makes the problem more challenging, participants could have been stimulated to more deliberately seek out connections (using System 2 processing) beyond clichés and mundane associations (Sowden et al., 2015). Third, we can consider regulatory focus theory from social psychology. The apparent mismatch (“nonfit”) between regulatory focus and task strategy (e.g., promotion focus paired with vigilance strategy or prevention paired with eagerness) has been found to create a sense of “wrongness” (Higgins, 2012). This discomfort, ironically, would make participants think they are not producing as many solutions as they possibly can, motivating them to push themselves further (for a fuller discussion, see Levine et al., 2016). Similarly, to stay vigilant on the potential risk of violating given constraints, which appears to be in discord with the motivation for unbound creativity, paradoxically, could have motivated it. Further research could clarify which variable has a greater explanatory power (e.g., cognitive, social, or both). Whichever the exact mechanism, there seems to be ample evidence that a lack of constraints (or negative freedom, Carter, 2022) is not always liberating for creativity, while some are liberating (enabling) constraints.

For exploratory purposes, we compared the two conditions on *O-F* and *O-U-F* (*by count*) of solutions decided upon by groups, which showed no differences (Research Questions 1 and 2).

### Limitations

This study has several limitations. As mentioned above, cluster-randomized design power analyses revealed that our sample (55 three-person groups) to detect a small to medium effect size in Hypotheses 1 to 3—the temporal performance changes—was sufficient with 80% power. For testing the mean performance differences between the two conditions, however, this sample could detect a medium effect with only 61% power, so there is likelihood that we did not detect the true effect for Hypotheses 4 and 5. However, this is a novel study, and future studies should consider replicating our findings with more power with larger sample sizes. The *unconstrained* condition did not have a rule that contrasts with the stay-focused rule. In fact, pitting the set of rules with the new stay-focused rule against one without it is informed by and extends the current literature (see Hypothesis 4; Putman & Paulus, 2009). Future work could test a cognitively *constrained* norm against an *unconstrained* norm that has a contrasting rule (e.g., “Do not stay focused on given information.”)

## Conclusion

Our results challenge the conventional wisdom that we should have a lengthy meeting to obtain more original solutions from later options. Also, including the distinctive rule to stay focused on task information potentially revises our understanding of the effective norm for creative problem solving. This is the first study on the reversed serial-order effect and the constraint effect using hybrid solution generation. Further research is needed to replicate and determine the effects of the cognitive and social variables associated with this understudied problem-solving paradigm.

# Study III: Freedom for Creativity or Cognitive Dissonance under Inductive, Deductive, and Abductive Norms of Reasoning: An Empirical Study Using fNIRS


## Abstract

Creativity is promoted through abductive (hypothetical) reasoning, while inductive (data-driven) or deductive (rule-based) reasoning equally suppress it—according to management and organizational theorists. We report the first empirical findings regarding this claim. A novel design was used to compare the effects of these three major reasoning norms on creative cognition, performance, and self-reported cognitive consonance. In Study III-1, we hypothesized not only that (1) abduction would indeed be most conducive to creativity, but also that (2) deduction would outperform induction. The reasoning norms were tightly defined, and there was a moderately high performance pressure to emulate organizational dynamics. The first hypothesis was supported by both neural and behavioral data and the second by only behavioral data. Study III-2 compared loose forms of the same reasoning norms along with less performance pressure than Study III-1. Data from Study III-2 suggest that induction when conceptualized as analogical reasoning may be a comparable approach to creativity as deduction and abduction. In sum, findings (1) support the superiority of the abductive norm for creativity. Data also suggest the creative values of the millennia-old analogical-inductive and deductive reasoning, which (2) challenges the long-standing literature that abduction is the exclusive path to creativity and (3) integrates the creativity literatures on abductive and analogical reasoning. The study was pre-registered and had sufficient power (over 90%) to detect small effects.

Reasoning type—such as induction, deduction, or abduction—is one of the most fundamental forces shaping human reasoning across different domains (Habermas, 1978; Johnson-Laird, 2015; Joullié, 2016; Lieberman, 2013). These domains include creativity, which is a product of intensive human reasoning (Csikszentmihalyi, 1997; Sawyer, 2012), both top-down (deliberate) and bottom-up (intuitive) (DeYoung et al., 2002; Johnson-Laird, 2015; Sawyer, 2012; see Abraham, 2018; Beaty et al., 2014; Kahneman, 2011; Nijstad et al., 2010; Sowden et al., 2015 for the dual-process theory of creativity). Leading management and organizational researchers (e.g., Dunne & Martin, 2006; Liedtka, 2004; Martin, 2009; Sætre & Van de Ven, 2021; Weick, 2005, 2006a, 2006b) have claimed that abduction is most conducive to creativity. However, no studies have directly tested it empirically. Answering calls for research on the effects of these three reasoning types (Holyoak, 2012; Wertheim & Ragni, 2018), we directly manipulate reasoning type in randomized experiments.

**Induction and Deduction**

Induction and deduction are the two most basic and commonly recognized reasoning types (Goel & Dolan, 2004; Green, 2018; Holyoak & Morrison, 2012; Johnson-Laird, 2015; Lieberman, 2013; Mantere & Ketokivi, 2013; Martin, 2009; Sætre & Van de Ven, 2021; Skinner, 1984; Weick, 2005). Induction is to reach an idea based on repeated past experiences. Deduction syllogistically arrives at an idea from certain rules or premises. The two are powerful tools to predict (deduction) and to generalize (induction) with high certainty (Nisbett et al., 1983; Tversky & Kahneman, 1983). Through these two, however, it is difficult to achieve creativity (Habermas, 1978; Martin, 2009; Peirce, 1955; Weick, 2005). (Creativity can mean both divergent idea generation and convergent idea selection [Paulus et al., 2019]. For simplicity, Study III uses "creativity" to refer to divergent idea generation.) This is because induction and deduction focus on repeated past data and logical rules, respectively, and on providing exceptionally high confidence in ideas derived through them (Martin, 2009; Weick, 2005). Creativity is generating what has not existed in the past, thus original (Guilford, 1950)—unlike induction, which repeats the past. Creativity also entails not only logical rule-based but, unlike deduction where logical steps are paramount, also intuitive associative processing (see Abraham, 2018; Kahneman, 2011; Sowden et al., 2015). Relatedly, creative or original ideas are weakly or inversely related to feasibility (Berg, 2014; Goncalo & Staw, 2006; Howell & Higgins, 1990; Lucas & Mai, 2022; Perry-Smith & Mannucci, 2017; Mueller et al., 2012). Creative ideas entail risk rather than offering a sense of high certainty, while induction and deduction specialize in offering high certainty (Martin, 2009; Peirce, 1878). Thus, induction and deduction have been considered instrumental in critical decision-making, rather than generating creative alternatives (Dunne & Martin, 2006; Habermas, 1978; March, 1976; Sætre & Van de Ven, 2021).

## Abductive Reasoning

Abductive reasoning, making an informed, probable guess for a given problem in the presence of incomplete information (Peirce, 1955), is the third basic reasoning type (Holyoak & Morrison, 2012; Johnson-Laird, 2015; Liedtka, 2004; Mantere & Ketokivi, 2013; Martin, 2009; Peirce, 1878; Sætre & Van de Ven, 2021; Weick, 2005). A long-standing body of research suggests that abduction is the heart of creativity and the only one among the three types of reasoning that introduces any genuinely creative ideas, while induction and deduction are either inapt for creativity or even stifle it (see Abolafia, 2010; Cross, 1990; Dunne & Dougherty, 2016; Dunne & Martin, 2006; Güss et al., 2021; Habermas, 1978; Liedtka, 2004; March, 1976; Martin, 2009; Sætre & Van de Ven, 2021; Weick, 2005, 2006).

As an example, say it is before 2007, when only feature phones existed, and you want to launch a new cellphone that will be successful. Inductively speaking, “Because feature phones by Motorola, Blackberry, Sony Ericsson, and so on, all sold well” (past data), you might think that “All feature phones sell well” (conclusion). Then, you add a new feature phone to the market (uncreative solution). Deductively, “Because all feature phones sell well, and we have been a feature phone manufacturer” (logical rules rooted in past data), you might think “Our new feature phone will sell well” (conclusion). Then, you similarly launch a new feature phone (uncreative solution). Abductively, you start with an end goal to be innovative (aspired result), you guess that they will probably love a phone that functions as a television, a computer, and has a touch-sensitive screen (conclusion) (Dorst, 2011). Then, you develop it (creative solution), which Steve Jobs did. The critical difference lay in reasoning rather than technology (Martin, 2009), as the scientific and engineering bases of smartphone had been known since the 1990s (Woyke, 2014). (Of the two—explanatory and innovative—kinds of abduction subsumed in Peirce’s [1878] original notion of abduction, Study III specifically refers to the innovative type that is used in creative reasoning, Dorst, 2011; Habermas, 1978; Roozenburg, 1993). The informed, probable guess of abduction involves more risk than an inductive or deductive solution as it may well be wrong (People may not like it!) Yet, abduction encourages free exploration and thought experimentation beyond the limited and fragmented information from the past we usually get, and abduction encourages reaching a reasonable conclusion even in the absence of unequivocal logical grounds (Hartwright et al., 2014). If freedom is crucial component of creativity, which it is (Dougherty, 1996; Hoffmann, 1999; Locke et al., 2008), so is abduction, because its agent is “free to control” their reasoning to generate ideas (Anderson, 1987, p. 44).

**Table 15**

*Descriptions of reasoning norms (I: induction; D: deduction; A: abduction).*

| | I | D | A |
|---|---|---|---|
| Process | from multiple instances to general principles | from general principles to specific instances | from unknown to informed guess |
| Criterion | empirical truth | logical validity | plausibility |
| Confidence | high | high | low |
| Divergent Thinking | difficult | difficult | easy |
| In Organizations | promoted | promoted | ignored |

### Freedom from Past-Bound Rationality

Norms are assumptions and values of an individual or a group manifested in their cognitive, linguistic, and behavioral patterns (Schein, 1984). A norm determines the boundaries of a valid way to reason for or rationalize an idea (Csikszentmihalyi, 1997; Dunne & Martin, 2006; Sawyer, 2012; Weick, 2005). Induction is the logic of what "is operative" and deduction what "must be" (Peirce, 1998, p. 216). Since both are based on available past data, no new idea can be proven effective inductively or deductively. By contrast, abduction, which is the logic of what "may be" or what is "possible" (Morris, 1992, p. 94), can validate a new idea. In other words, the abductive norm of reasoning encourages generating unproven yet promising ideas (Dunne & Martin, 2006, p. 513; Martin, 2009, p. 63; though all three reasoning types are found within a single creative thought when we dissect it; see Roozenburg, 1993; Roozenburg & Eekels, 1995).

Ironically, individuals, teams, and organizations that want to be creative are "mostly dominated" by inductive and deductive reasoning (Martin, 2009, p. 27). One reason might be our natural implicit biases toward familiarity (see Tversky & Kahneman, 1973) and against originality (Mueller et al., 2012). These tendencies would better fit with reasoning based on past data such as induction or deduction. Another reason is that—due to "norms of rationality and uncertainty reduction" (Weick, 2005, p. 433)—modern education and organizations tend to discourage individual members from expressing original or nonconforming ideas (Dunne & Dougherty, 2016; Martin, 2009; Nemeth, 1986). Norms of error prevention aim to ultimately create fail-safe processes (Cowley, 2021; van Dyck, 2005). These prevalent social and organizational norms of rationality, based on already-available past data (induction) or known logical rules based on such data (deduction), tend to minimize uncertainty rather than taking reasonable risks based on informed guesses (abduction) (Martin, 2009; Peirce, 1878; Weick, 2005).

Faced with creative problems, however, there are at least two issues with induction and deduction. First, as discussed, to be creative is to generate something that has not existed, so the norms of rationality using induction and deduction are severely bounded by limited reference points from the past (Martin, 2009; see also March, 1978; Simon, 1957, 2000 on bounded rationality). After a member of a team or organization thinks of an idea, the person needs to then justify the insight by providing a reason that aligns with their shared norm of reasoning. This is because, in social or organizational contexts, an idea must be expressed, persuaded, and accepted by others in order to have any creative effect (Csikszentmihalyi, 1997; Sawyer, 2012), so that generating ideas inevitably takes a form of communication (Girotra et al., 2010). Here, past-experiences-bound inductive and deductive reasoning would be unfit for communication of imagined future courses of events. Second, a creative insight is considered often—though not always—coming to our consciousness in a split, Eureka ("Aha!") moment (Jung-Beeman et al., 2004; Kounios & Beeman, 2014). During this experience, a person suddenly becomes aware of both a form of a novel solution and its operational mechanism simultaneously (Dorst, 2011; Roozenburg & Eekels, 1995). Such experience seems distinct from attention directed on repeated past events (induction) or logical rules (deduction).

For these reasons, cognitive and behavioral processes of the inductive and deductive norms would disrupt a person's schematic expectations of how to generate creative ideas. The conflict between externally imposed norms and internal beliefs would result in cognitive dissonance, which has been associated with a lack of cognitive control, reduced motive fulfillment (performance), and aversive affect toward the norm (Festinger, 1957; Ludwig et al., 2020; Minas et al., 2014; Sun, 2016). Reasoning norms that contradict with creative idea generation would involve different routes to dissonance reduction: Individuals would be motivated to justify their compliance with the uncreative norms by modifying their beliefs about how to generate creative ideas, adjusting their behavior to generate any—rather than creative—ideas, and/or distorting their perception of the creative standard (Festinger & Carlsmith, 1959; Festinger et al., 1956; Harmon-Jones & Harmon-Jones, 2007). Either of these dissonance reduction strategies would damage creative cognition, performance, and experience.

To counteract failures of creativity, individuals and teams thus may have to "replace" inductive and deductive thinking with abductive thinking (Weick, 2005, p. 436). Or the norm should at least assure that "it is safe" to "bring forward an abductive argument" (Martin, 2009, p. 28). In this vein, researchers agree that, under creative goals, abduction needs to become the predominant norm of reasoning (Dunne & Martin, 2006; Liedtka, 2004, 2018; Martin, 2009; Sætre & Van de Ven, 2021; Weick, 2005, 2006). Nonetheless, how people with creative goals actually behave regarding each of the three reasoning norms has not been empirically tested, as previous research has been either theoretical (e.g., Dong et al., 2016; Galle, 1996; Garbuio &

Lin, 2021; Green, 2018; Johnson-Laird, 2010, 2015; Ketokivi & Mantere, 2010; Kolko, 2010; Locke et al., 2008; Mantere & Ketokivi, 2013; Martin, 2009; Roozenburg, 1993; Roozenburg & Eekels, 1995; Sætre & Van de Ven, 2021; Weick, 2005), qualitative (e.g., Abolafia, 2010; Dunne & Dougherty, 2016; Dunne & Martin, 2006; Güss et al., 2021), using non-creative tasks (e.g., Goel & Dolan, 2004; Goel et al., 1997, 1998; Hartwright et al., 2014; Rips, 2001; Wertheim & Ragni, 2018), comparing only two of the three reasoning types (e.g., Hartwright et al., 2014; Wertheim & Ragni, 2018), using computer programs instead of involving human participants (e.g., Wagner, 1996), testing idea selection rather than idea generation (e.g., Dong et al., 2015), or treating reasoning types as the dependent—instead of independent—variable (e.g., Cramer-Petersen et al., 2019). Therefore, the case is still open for empirical comparison of different degrees of creative cognition, performance, and experience caused by the reasoning norms.

**Deduction—Equally Suppressive?**

Furthermore, it would be a serious oversight to disregard creative potentials of induction and deduction since they are the most commonly recognized reasoning types (Dunne & Martin, 2006; Lieberman, 2013; Martin, 2009; Sætre & Van de Ven, 2021). Thus, next in importance to our question of the superiority of abduction over induction and deduction for creativity is: “Do induction and deduction (equally) curb creativity?” Though indirectly, many have suggested that they do (see Dunne & Martin, 2006; Habermas, 1978; Locke et al., 2008; Mantere & Ketokivi, 2013; Martin, 2009; Sætre & Van de Ven, 2021; Weick, 2005; cf. Green, 2018). Identifying induction with deduction in its creative potential seems legitimate on one hand. According to Peirce (1998, p. 216), “Induction does nothing but determine a value,” based on available past data; “Deduction merely evolves the necessary consequences of a pure hypothesis,” based on logical rules; while abduction is “the only logical operation which introduces any new idea” (Sætre & Van de Ven, 2021), for the reasons discussed above.

On the other hand, however, researchers have introduced at least three insights based on additional understanding of Peirce regarding deduction. First, deduction and abduction share a key similarity—that hypothetical (if-then) reasoning is possible for both (Johnson-Laird & Wason, 1977, p. 79; Wagner, 1996). Abduction is hypothetical because it is essentially an informed guess, but so is deduction if its premises are hypothetical, for example, “If consumers love a phone with the functions of a television, a computer, and with a screen that is touch-sensitive, and if we make such a phone” that lead to “Then, consumers will love our phone.” Deduction and abduction, in other words, can similarly draw upon mental simulation of hypothetical future events (Byrne & Johnson-Laird, 2009; Hoffmann, 1999; Johnson-Laird 1995; Johnson-Laird et al., 1992), and thereby introduce novel ideas (for examples see Galle, 1996; Wagner, 1996). This leaves induction the only reasoning norm that is unamenable to generating novel ideas, because an inductively envisaged future event is only one that has been repeated in the past.

Second, Peirce was aware that while deduction does not yield brand-new information, it does make explicit what was implicit and concealed in the known data (Morris, 1992; Wagner, 1996). Consider this example of a deductive argument, “All consumers desire the functions (a television and a computer with a touch-sensitive screen) of a smartphone. We can manufacture a smartphone. Therefore, the functions of what we can manufacture will be highly desired.” Even if one knew that all consumers desire what smartphone can do for them, it may not have been obvious to the person that what they could produce would be highly sought-after in the market. So, deduction can reveal a concealed connection and bring to consciousness what was logically necessary but unconscious to the thinker. The revealed connection can "come as a surprise" and thus be considered "novel" (Wagner, 1996, p. 109). The sense of newness will be even greater when the revealed connection contradicts our prior intuitions (Green, 2018)—for example, when a prior intuition that feature phones are associated with success is contradicted by a revealed connection that it should be a smartphone that we manufacture in order to greatly succeed (prior to 2007, when smartphones did not exist).

Lastly, deduction proceeds logically step-by-step from explicit premises, so that its conclusion is almost certainly true if premises are true. By contrast, abductive reasoning unfolds intuitively, following a Gestalt-like process (Morris, 1992, p. 96), without explicit and controlled steps of thought (Hoffmann, 1999; Morris, 1992). Notwithstanding the higher risk of error for intuitive processing (Smith & DeCoster, 2000), due to the less cognitive demand for controlled processing, abduction would be easier than deduction for idea generation. Based on these three points, we expect deduction will better facilitate creativity than induction, but less so than abduction.

## Study III-1

### Hypotheses

#### *Brain Activity*

We expect the superiority of abductive reasoning for creativity over induction and deduction as well as deduction over induction, to be evidenced in increased activity in creativity-related brain regions of interest (ROIs). Creativity is fundamentally an outcome of intensive reasoning—both bottom-up (intuitive) and top-down (deliberate) (Kahneman, 2011; Nijstad et al., 2010; Sowden et al., 2015). Thus, we focus on the prefrontal cortex (PFC), which specializes in high-level cognition and has consistently shown increased activity during a wide array of creative paradigms (Abraham, 2018; Dietrich & Kanso, 2010; Khalil et al., 2019).

Note also that creativity in cognitive terms is defined as the (1) “selective retrieval” and (2) “combination” of (3) distant but “relevant” information into (4) “novel” ideas, while (5) “focused” on the creative goals (Beaty et al., 2016, p. 87; Benedek, Jauk, et al., 2014, p. 125; George & Wiley, 2019, p. 306; Paulus & Brown, 2007, p. 252). Even though brain regions serve multiple purposes and work as networks rather than isolated regions (Raichle, 2015; Seeley et al., 2007), research has revealed localized brain activation with specific relevance to this definition of creative cognition. The ventrolateral prefrontal cortex (VLPFC), particularly its left-lateralized activation, is implicated in “selective retrieval” of information and in “focused” attention for this process (Badre & Wagner, 2007; Petrides, 2005; Thompson-Schill, 2003). The ventromedial prefrontal cortex (VMPFC) is associated with evaluating “relevance” of information (Fareri & Delgado, 2014; Oldham et al., 2018; Winecoff et al., 2013) and “combining” them (Bartra et al., 2013; Lin & Vartanian, 2018; Walton et al., 2015). The dorsolateral prefrontal cortex (DLPFC), particularly its right side (Duncan & Owen, 2000; Seeley et al., 2007), is involved in monitoring task-relevant information such as “goals” and simulating imagined future scenarios (Madore et al., 2016; Petrides, 2005). The dorsomedial prefrontal cortex (DMPFC) has been involved in making analogical connections (Goel et al., 1997) and future thinking (Abraham et al., 2008). These respective functions, among others, of the regions may explain why during creative tasks increased activity was found in them (e.g., the VLPFC, Kröger et al., 2012; Rutter et al., 2012; Shah et al., 2013; the VMPFC, Abraham et al., 2012; Benedek et al., 2020; the DLPFC, Beaty et al., 2015; Shah et al., 2013; Takeuchi et al., 2010; and the DMPFC, Abraham et al., 2012; Benedek, Beaty, et al., 2014).

Therefore, activity in the PFC and its subregions (the VLPFC, the VMPFC, the DLPFC, and the DMPFC) is expected to be the highest during abduction compared with induction and deduction (although using fNIRS, we have limited access to the VMPFC), and higher during deduction than induction.

### *Idea Quality*

Consistently with neural measures, we expect behavioral measures to result in the same patterns. Abductive reasoning would lead to generating ideas that are most *original*, and induction the least. *Originality* is a sense of unusualness (rated using content analysis; see Method; Amabile, 1982, 1993), and is considered the hallmark of creativity (Nijstad et al., 2010; Rietzschel et al., 2010; Stroebe et al., 2010). An additional measure of creativity is feasibility (the degree to which an idea can be easily implemented, Guilford, 1950; Rietzschel et al., 2010), which tends to be weakly or inversely correlated with originality (Berg, 2014; Goncalo & Staw, 2006; Howell & Higgins, 1990; Lucas & Mai, 2022; Perry-Smith & Mannucci, 2017; Mueller et al., 2012). Thus, we expect higher originality under the abductive norm, while exploring the pattern of feasibility across the reasoning norms.

### *Cognitive Dissonance*

Following one of the reasoning norms to generate creative ideas would cause either cognitive consonance, its agreement with one’s beliefs about creative thinking, or dissonance, a cognitive inconsistency (Festinger, 1957). In accordance with cognition and performance, participants will likely self-report abduction as the most, and induction the least, cognitively consonant with creativity.

## Method

### *Participants*

All 18 participants were undergraduate and graduate, right-handed, native English-speaking students from a large Midwestern university in the United States. They participated for a monetary compensation. The study was approved by the university IRB and was pre-registered at the OSF (https://osf.io/mwtk6/?view_only=6f0d5e8416074f6fbb65784481dcdbb5). The experiment involved three (inductive, deductive, and abductive) within-subject conditions, repeated measures, and task repetition. Power analysis using the “simr” package in R suggested that 12 participants with 45 trials per participant (15 trials x 3 conditions) would be sufficient to have more than 90% power to detect a small effect size ($\omega^2 = .01$). Therefore, the study was sufficiently powered with 18 participants to detect relatively small effects.

***Procedures***

**Task.** The alternative uses task (AUT) has extensively been used as a domain-general behavioral measure for divergent creative thinking. During this task, participants are given a common object (e.g., a brick, fork, pencil, etc.) and asked to generate unconventional uses for it. A novel study design with three (inductive, deductive, and abductive) variations of AUT was developed by using plain English to instruct participants of the three reasoning requirements, instead of presenting the terms, “induction,” “deduction,” and “abduction.” In so doing, we consulted the literature (e.g., Dorst, 2011; Habermas, 1978; Johnson-Laird, 2015; Liedtka, 2004; Martin, 2009; Peirce, 1878; 1955, 1998; Weick, 2005) and philosophy professors with expertise on logic. Induction is passing from many repeated past cases (to a hidden general principle and then) to an idea, so the inductive AUT asked participants to generate creative ideas from “many same past experiences” with the identical object. Deduction is reaching an idea from a general principle, rule, truth, or pattern, so the deductive AUT condition asked participants to generate ideas from “general characteristics” of the object. Abduction is envisioning something (“what”) and its mode of operation ("how") to achieve the given outcome, so the abductive AUT condition asked participants to generate ideas from "possibility" of how something would operate. Induction, deduction, and abduction conditions were communicated to participants as "many same past experiences," "general characteristics," and "possibility" rules, respectively.

Prior to visiting the fNIRS laboratory, participants completed a questionnaire on their psychosocial characteristics. Upon arriving at the experimental site outside the fNIRS lab, participants were told that their task would involve generating creative ideas while following one of three rules at a time. The experimenter made clear the expectation that participants should generate only highly creative ideas and that their final creativity score would suffer if they generated ideas that are mundane. Then they received one-on-one training on all three (inductive, deductive, abductive) AUTs. The training protocol was developed based on pilot-testing and debriefing with nine participants. The experimenter showed participants the first examples of how to generate creative ideas for an everyday item by following the three rules ("many same past experiences" for induction, "general characteristics" for deduction, and "possibility" for abduction) and to provide a reason that abides by one of the rules for each idea. To indicate commitment to each norm, participants were required to include specific linguistic marks in the reason part of their response: "Many times before" and a past-tense verb to describe past direct or indirect experiences with the given object for induction; "all/every/always" and a characteristic or property of the object for deduction; and "can/could/might" and a potential working mechanism for abduction. Then, they were given the exact definition for each rule: "Many same past experiences" is briefly mentioning many previous cases with the same object as reason; "General characteristics" is mentioning any of its general/common/universal qualities; and "Possibility" is how it might plausibly be used. Participants were also given additional explanations about the task such that they should try to generate as many creative ideas as they could, state their reason as briefly as possible not writing a full sentence, and that reason for each idea should be sensical. Then, the experimenter showed the first examples again for participants to understand the task more fully in light of the definitions. Participants were then given the first practice session to generate by themselves three creative ideas, one for each rule, for an everyday object. After the first practice session, participants engaged in the second set of examples and practice, and then the third. Finally, participants reviewed the definitions and additional explanations. At each step, participants were given ample time to understand the task and were encouraged to ask any questions. The experimenter did not advance to the next step of the training when participants' response during practice did not meet the rule. Training lasted 15 to 25 minutes until the experimenter was certain that participants fully understood the tasks. (In a separate manipulation-check study, 31 undergraduate participants who underwent the same training scored 94.6% on 18 questions about distinguishing the three rules.)

After completing the training, participants entered the fNIRS booth and completed one practice trial for each condition. A practice trial was identical with the actual task except for the final reminders of the definitions and explanations of the rules and the reminder to not generate any ideas that do not follow any of these instructions. A trial would begin with a "Ready?" cue (2s) on the screen in front of them, and an idea generation period (35s) followed during which participants were presented with an object in text and an image (e.g., "brick" and an image of a brick) at the top of the screen under which came one of the rules, and the remaining time at the bottom. Participants did not type during this section and were instructed to think of ideas. Then, a response period (30s) required participants to type out ideas and a reason for each idea that they generated. The providing of reason was (1) in order to induce participants to actually follow each reasoning pattern and (2) because in social/organizational settings where no innovation takes place in a social vacuum, one has to communicate the idea based on the norms of reasoning shared within the group, team, or organization. Lastly, there was a resting period (15s) with images of natural landscapes for ten seconds and a fixation cross for five seconds.

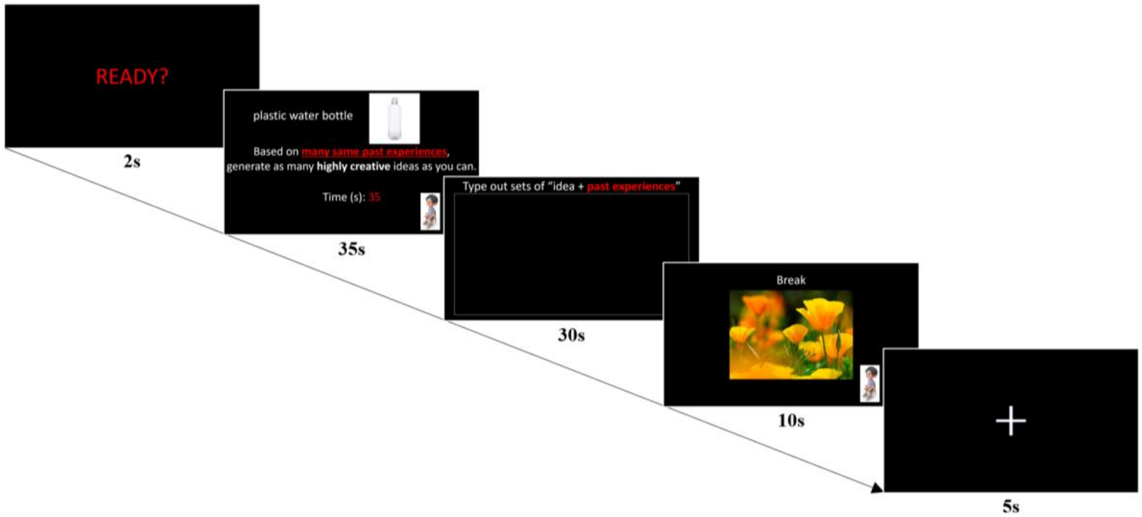
For the actual task, each condition had 15 trials (i.e., 3 x 15 = 45 total trials). Each trial involved a different everyday object, so there were overall 45 objects to match the 45 overall trials administered in a block design. There were 5 rounds of 9 trials each. The 9 trials within each round were consisted of 3 sets, each set comprising 3 conditions being presented in a random order within the set. 9 objects in each round appeared in a random order within the round. Thus, objects and conditions were paired in a near-random and unpredictable order to participants. At the end of the 2-minute break between each round, the experimenter reminded participants of the importance of leaving linguistic marks, generating only highly creative ideas, and not generating ideas that do not follow the instructions.

**Figure 7**

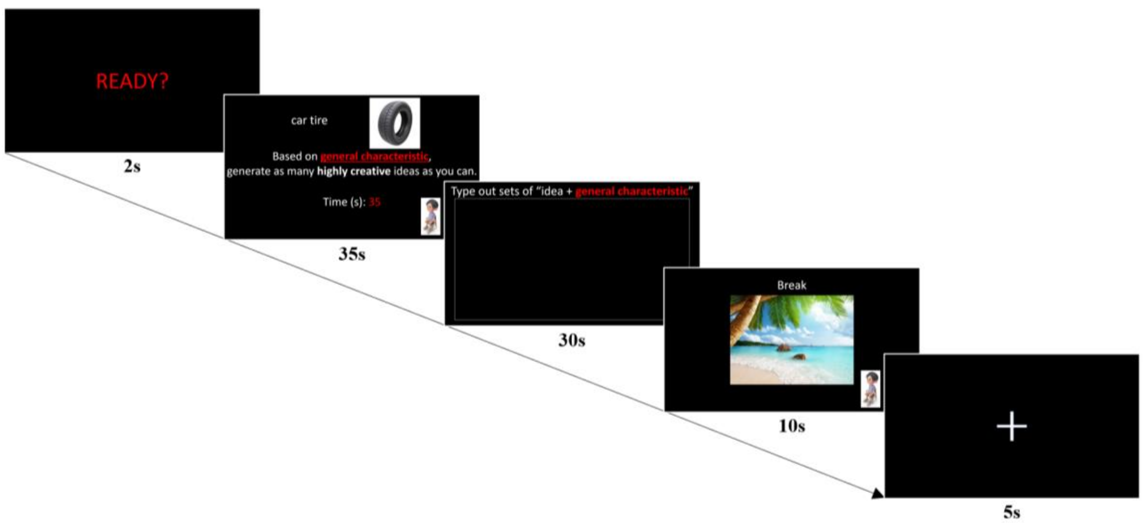
*Experimental settings. (a) A semi-naturalistic environment of the experiment. Participants sit on a chair, think, and type their thoughts while their brain activity is scanned with fNIRS. (b) Inductive AUT. (c) Deductive AUT. (d) Abductive AUT.*

(a)

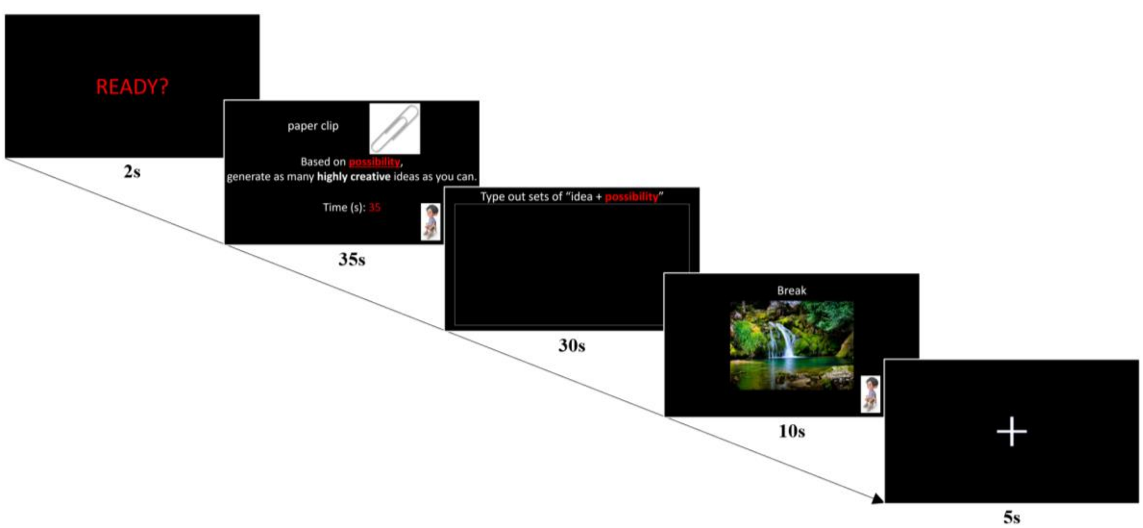
(b)


READY?
2s
plastic water bottle
Based on many same past experiences,
generate as many highly creative ideas as you can.
Time (s): 35
35s
Type out sets of "idea + past experiences"
30s
Break
10s
+
5s

(c)


READY?
2s
car tire
Based on general characteristic,
generate as many highly creative ideas as you can.
Time (s): 35
35s
Type out sets of "idea + general characteristic"
30s
Break
10s
+
5s

(d)


READY?
2s
paper clip
Based on possibility,
generate as many highly creative ideas as you can.
Time (s): 35
35s
Type out sets of "idea + possibility"
30s
Break
10s
+
5s

Upon completing the task, participants completed a post-task survey, were debriefed, and thanked for their participation.

**Behavioral Measures.** ***Quality of Ideas***. Three independent trained raters coded *originality* and *feasibility* (see Lu et al., 2019, 2020; Nijstad et al., 2010; Rietzschel et al., 2010) of each of 1,826 ideas participants generated. The raters were blind to both condition and reason for each idea, and given only the idea part to evaluate. A *1* (*lowest*) to *5* (*highest*) scale was used for both dimensions. Raters were considered to be in agreement whenever all three scores fell within one point on the scale of every other coder (Diehl & Stroebe, 1987, 1991; Paulus et al., 2013, 2015; Rietzschel et al., 2006). The Krippendorff's alpha ($\alpha$) inter-rater reliability on 540 ideas was sufficiently high (.887 for *originality* and .855 for *feasibility*). Each rater then coded one third of the remaining ideas. ***Cognitive Dissonance.*** 15 items on *norm preference*, *perceived performance*, and *task comfort* were adopted from Ajzen and Madden (1986) and Sun (2016). Each item was measured on a Likert scale of *1* (*strongly disagree*) to *7* (*strongly agree*). *Norm preference* used 3 items (e.g., "I was personally inclined to use [past experience/characteristic/possibility] to generate creative ideas"; Cronbach's $\alpha$ = .78, .66, and .51 for induction, deduction, and abduction, respectively) to assess the willingness to observe each reasoning type. Participants were told that "past experience," "characteristic," and "possibility" represented the rules of "many same past experiences," "general characteristics," and "possibility," respectively. Participants were not exposed to the logical terminology such as induction, deduction, and abduction. *Perceived performance* was measured with 9 items (e.g., "Using [past experience/characteristic/possibility], I had a lot of freedom of thought," "Using [past experience/characteristic/possibility], I was completely in control to generate creative ideas," "Using [past experience/characteristic/possibility], I could generate more creative ideas,";

Cronbach's $\alpha$. = .92, .88, and .84, respectively) on the degree to which each reasoning norm fit the creative task. *Task comfort* used 3 items (e.g., "Using [past experience/characteristic/possibility], I was more relaxed to generate creative ideas"; Cronbach's $\alpha$. = .88, .76, and .85, respectively) to assess task self-efficacy under each reasoning. See Appendix B for survey items.

**fNIRS Recording and Signal Processing**

The study employed functional near-infrared spectroscopy (fNIRS, NIRScout 16x16; NIRx Medical Technologies, LLC.). fNIRS is a non-invasive neuroimaging technique that uses near-infrared light to monitor neuronal activity-related changes in (de)oxygenated hemoglobin and that allows tests to be done in an ecologically friendly surroundings. fNIRS introduces no noise, tolerates some body movement, and allows participants to sit up right during the task, which provide the most naturalistic environment for neuroimaging research (Noah et al., 2015; Pinti et al., 2020). We used 32-channel array of optodes (16 emitters and 16 detectors) on an fNIRS cap according to the international 10/10 system placed on the prefrontal areas of each subject. The brain regions of interest (ROIs) were defined based on structures from the automated anatomical labeling (AAL) atlas and Montreal Neurological Institute (MNI) coordinates (see Cohen-Zimerman et al., 2019; Cristofori et al., 2016; Gozzi et al. 2009; Koenigs et al., 2007; Krueger et al., 2011; Tzourio-Mazoyer et al., 2002). A montage was constructed with 46 long channels that covered the VLPFC, part of the VMPFC, the DLPFC, and the DMPFC (Figure 8), as well as 8 short channels in order to extract the scalp-hemodynamic artifact. A distance of 25-40 mm for contiguous optodes and near-infrared light at two wavelengths (760 and 850 nm) were used for the recording. Based on Gozzi et al. (2009), the following channels have been acquired: Channels 6 (AFp1-AF5)/10 (AF3-Fp1)/12 (AF7-Fp1)/13

(AF7-F7)/14 (F5-F7)/15 (F5-AF5)/18 (FT7-F7)/19 (FT7-FC5) and channels 27 (AF4-Fp2)/29 (AF8-Fp2)/30 (AF8-F8)/31 (F6-F8)/32 (F6-AF6)/35 (FT8-F8)/36 (FT8-FC6) correspond to the left and right VLPFC (Brodmann Area [BA] 45/47); channels 2 (Fpz-Fp1)/5 (AFp1-Fp1) and channel 3 (Fpz-Fp2) to the left and right VMPFC (BA 10); channels 8 (AF3-AFz)/9 (AF3-AFF1h)/11 (AF3-F3)/16 (F5-F3)/17 (F5-FC5)/20 (F1-F3)/21 (F1-FC1)/23 (FC3-F3)/24 (FC3-FC5)/25 (FC3-FC1) and channels 26 (AF4-AFz)/28 (AF4-F4)/33 (F6-F4)/34 (F6-FC6)/39 (F2-F4)/40 (F2-FC2)/41 (FC4-F4)/42 (FC4-FC6)/43 (FC4-FC2) to the left and right DLPFC (BA 9/46); and channels 4 (AFp1-AFF1h)/22 (F1-Fz) and channels 37 (AFF2h-AFp2)/38 (F2-Fz) to the left and right DMPFC (BA 8/9).

**Table 16**

*Study III-1 ROI configuration of prefrontal subareas using NIRScout based on Gozzi et al. (2009)*

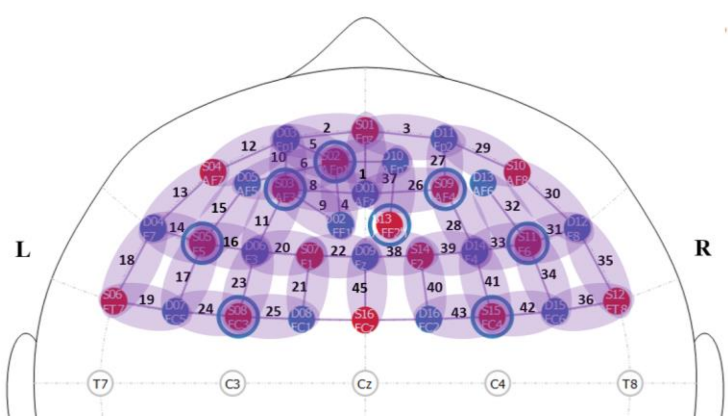
| ROI (Brodmann Area) / MNI coordinates | | | Channels with approx. MNI coordinates | | | |
|---|---|---|---|---|---|---|
| | | | # | x | y | z |
| VLPFC (45, 47) | Left | $x < -20$, $z \leq 1$ | 6 | -23 | 68 | 0 |
| | | | 10 | -21 | 59 | 1 |
| | | | 12 | -26 | 51 | -1 |
| | | | 13 | -36 | 41 | -6 |
| | | | 14 | -51 | 42 | -4 |
| | | | 15 | -38 | 49 | 1 |
| | | | 18 | -51 | 10 | -20 |
| | | | 19 | -60 | 6 | -1 |
| | Right | $x > 20$, $z \leq 1$ | 27 | 23 | 55 | 0 |
| | | | 29 | 31 | 55 | -2 |
| | | | 30 | 50 | 46 | -7 |
| | | | 31 | 41 | 40 | 1 |
| | | | 32 | 47 | 52 | 0 |
| | | | 35 | 63 | 17 | -17 |
| | | | 36 | 56 | 5 | 0 |
| VMPFC (10) | Left | $-20 \leq x < 0$, $z \leq 1$ | 2 | -9 | 60 | -5 |
| | | | 5 | -12 | 51 | 0 |
| | Right | $0 \leq x \leq 20$, $z \leq 1$ | 3 | 14 | 72 | -11 |

| | | | | | | |
|---|---|---|---|---|---|---|
| DLPFC (9, 46) | Left | x <−10 | 8 | -13 | 61 | 12 |
| | | z > 1 | 9 | -16 | 60 | 20 |
| | | | 11 | -25 | 46 | 9 |
| | | | 16 | -50 | 48 | 15 |
| | | | 17 | -40 | 19 | 14 |
| | | | 20 | -33 | 52 | 36 |
| | | | 21 | -22 | 37 | 52 |
| | | | 23 | -48 | 32 | 33 |
| | | | 24 | -54 | 15 | 28 |
| | | | 25 | -35 | 11 | 46 |
| | Right | x > 10 | 26 | 14 | 55 | 14 |
| | | z > 1 | 28 | 37 | 62 | 18 |
| | | | 33 | 38 | 32 | 9 |
| | | | 34 | 65 | 30 | 12 |
| | | | 39 | 26 | 47 | 31 |
| | | | 40 | 23 | 33 | 49 |
| | | | 41 | 54 | 36 | 35 |
| | | | 42 | 48 | 13 | 24 |
| | | | 43 | 34 | 14 | 39 |
| DMPFC (8, 9) | Left | −10 ≤ x < 0 | 4 | -7 | 56 | 15 |
| | | z > 1 | 22 | -9 | 50 | 40 |
| | Right | 0 ≤ x ≤ 10 | 37 | 13 | 72 | 22 |
| | | z > 1 | 38 | 15 | 54 | 47 |

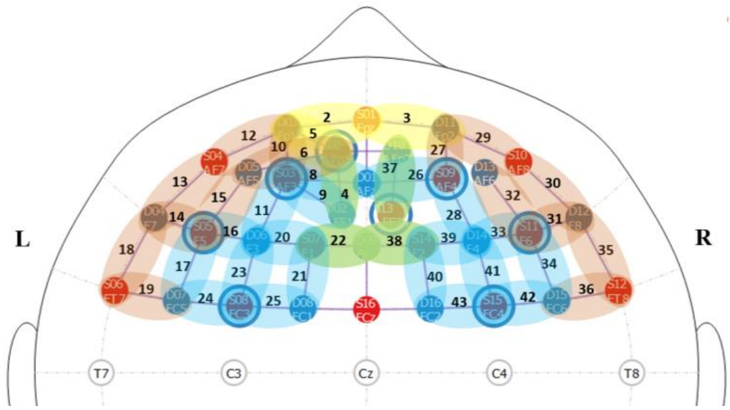
**Figure 8**

*Study III-1 fNIRS channel locations of the (a) PFC and the (b) PFC subareas—the bilateral VLPFC (red), VMPFC (yellow), DLPFC (blue), and DMPFC (green) using NIRScout.*

(a)



(b)




## Results

We used linear mixed-effects models to account for the nested data structure of the within-subject repeated measures design with three reasoning conditions. Significant findings are reported from pairwise contrasts of differences in neural and behavioral outcomes.

**Table 17**

*Study III-1 mean (SD) and pairwise comparisons of neural outcomes (N = 18)*

| | Comparisons | | | $t$ | $p$ | $\omega^2_p$ |
|---|---|---|---|---|---|---|
| PFC | I | | D | -1.08 | .286 | - |
| | I | < | **A** | -2.32 | .027* | 0.11 |
| | D | | A | -1.23 | .227 | - |
| Subregions | | | | | | |
| Left VLPFC | I | | D | -1.08 | .287 | - |
| | I | < | **A** | -2.33 | .026* | 0.11 |
| | D | | A | -1.25 | .220 | - |
| Right VLPFC | I | | D | 0.16 | .871 | - |
| | I | | A | -1.34 | .188 | - |
| | D | | A | -1.51 | .141 | - |
| Left VMPFC | I | | D | -0.30 | .763 | - |
| | I | | A | -1.09 | .282 | - |
| | D | | A | -1.40 | .171 | - |
| Right VMPFC | I | | D | 0.24 | .809 | - |
| | I | | A | -0.70 | .488 | - |
| | D | | A | -0.94 | .352 | - |
| Left DLPFC | I | | D | -1.19 | .241 | - |
| | I | | A | -1.43 | .162 | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| | D | | A | -0.24 | .814 | - |
| Right DLPFC | I | | D | -1.10 | .278 | - |
| | I | < | **A** | -2.70 | .011* | 0.15 |
| | D | | A | -1.60 | .118 | - |
| Left DMPFC | I | | D | -0.94 | .352 | - |
| | I | | A | -0.52 | .607 | - |
| | D | | A | -0.42 | .675 | - |
| Right DMPFC | I | | D | -0.33 | .747 | - |
| | I | | A | -1.18 | .248 | - |
| | D | | A | -0.85 | .401 | - |

*Note.* * $p < .05$. Bold font indicates significantly greater than the compared reasoning norm.

**Table 18**

*Study III-1 mean (SD) and pairwise comparisons of behavioral outcomes (N = 18)*

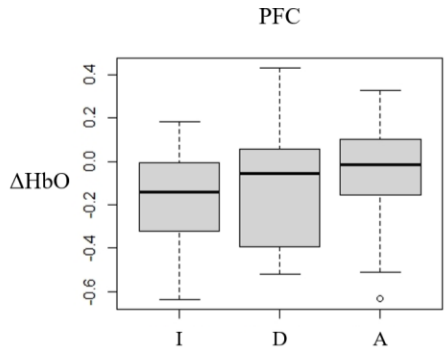
| | Comparisons | | | $t$ | $p$ | $\omega^2_p$ | Mean (*SD*) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | I | D | A |
| Idea quality | | | | | | | | | |
| *Originality* | I | < | **D** | -2.62 | .013* | 0.14 | 2.28 (0.29) | **2.49 (0.43)** | - |
| | I | < | **A** | -5.55 | < .001*** | 0.45 | 2.28 (0.29) | - | **2.73 (0.44)** |
| | D | < | **A** | -2.93 | .006** | 0.17 | - | 2.49 (0.43) | **2.73 (0.44)** |
| *Feasibility* | **I** | > | D | 2.62 | .013* | 0.14 | **3.89 (0.58)** | 3.68 (0.42) | - |
| | **I** | > | A | 3.27 | .002** | 0.21 | **3.89 (0.58)** | - | 3.63 (0.46) |
| | D | | A | 0.65 | .522 | - | - | 3.68 (0.42) | 3.63 (0.46) |
| Consonance | | | | | | | | | |
| *Norm Preference* | I | | D | -1.51 | .139 | - | 3.70 (1.82) | 4.41 (1.42) | - |
| | I | < | **A** | -5.55 | < .001*** | 0.45 | 3.70 (1.82) | - | **6.28 (1.03)** |
| | D | < | **A** | -4.03 | < .001*** | 0.30 | - | 4.41 (1.42) | **6.28 (1.03)** |
| *Perceived Performance* | I | < | **D** | -2.89 | .007** | 0.17 | 3.13 (1.51) | **4.22 (1.11)** | - |
| | I | < | **A** | -8.04 | < .001*** | 0.64 | 3.13 (1.51) | - | **6.17 (0.87)** |
| | D | < | **A** | -5.14 | < .001*** | 0.41 | - | 4.22 (1.11) | **6.17 (0.87)** |
| *Task Comfort* | I | | D | 0.25 | .808 | - | 2.35 (1.60) | 2.24 (1.20) | - |
| | I | < | **A** | -3.82 | .001** | 0.27 | 2.35 (1.60) | - | **4.07 (1.64)** |
| | D | < | **A** | -4.07 | < .001*** | 0.30 | - | 2.24 (1.20) | **4.07 (1.64)** |

*Note.* * $p < .05$; ** $p < .01$; *** $p < .001$. Bold font indicates significantly greater than the compared reasoning norm.

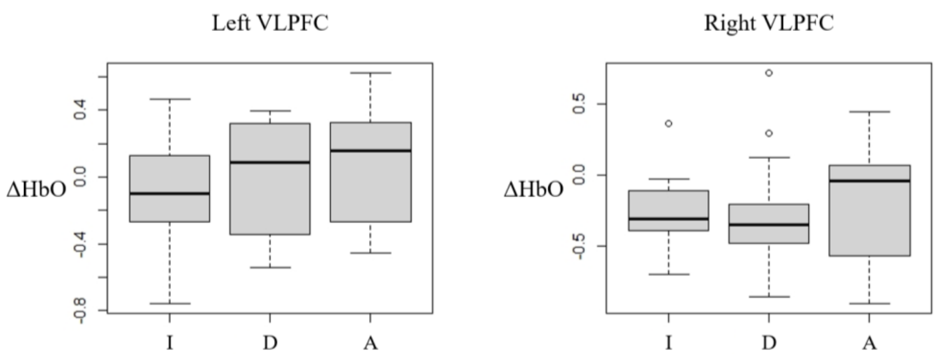
**Figure 9**

*Study III-1 activity in the PFC and its subareas by reasoning norm (a) PFC. (b) VLPFC. (c) VMPFC. (d) DLPFC. (e) DMPFC.*

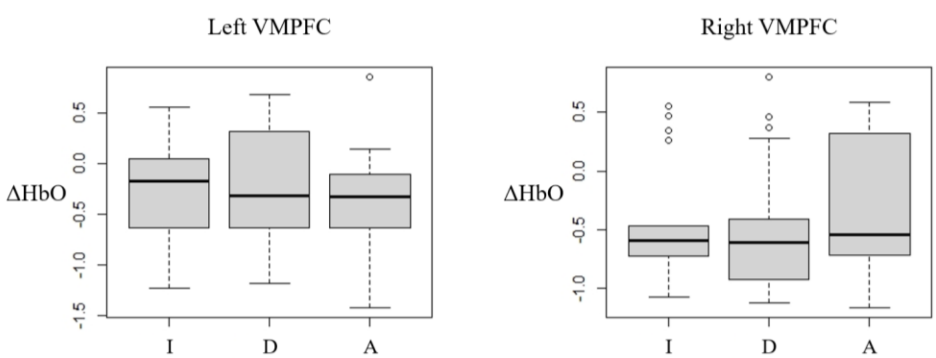
(a)



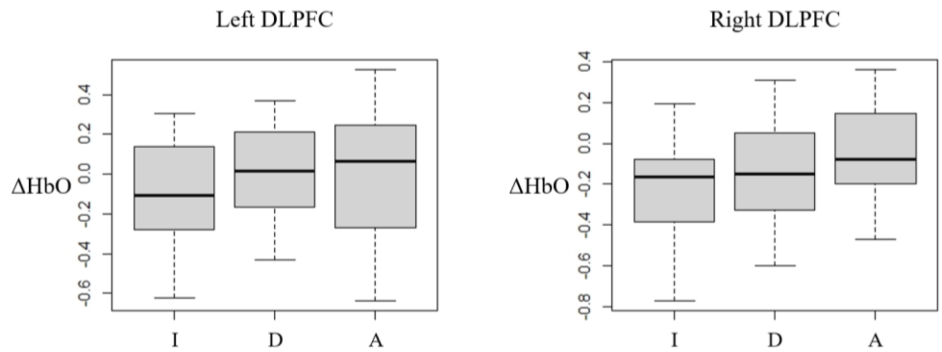

(b)




(c)



(d)




(e)

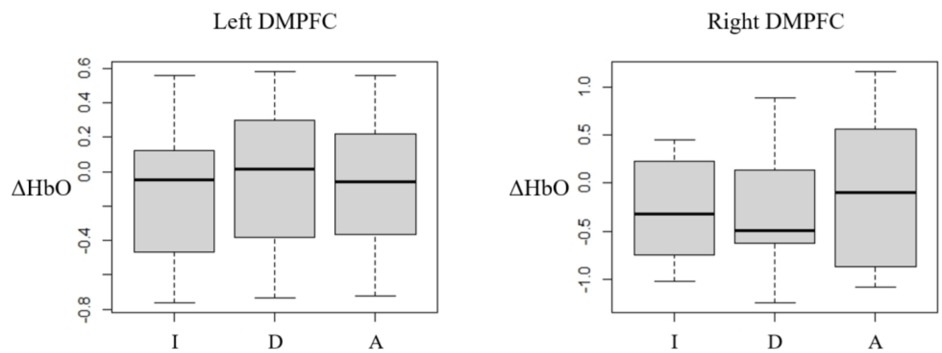



**Figure 10**

*Study III-1 idea quality by reasoning norm. (a) originality. (b) feasibility.*

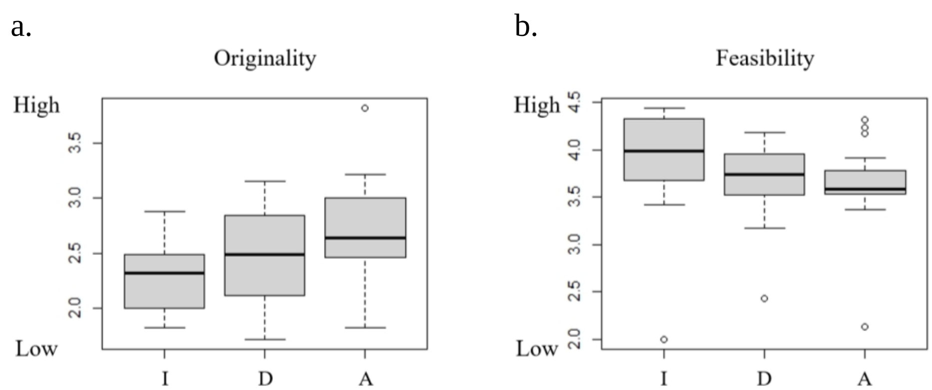
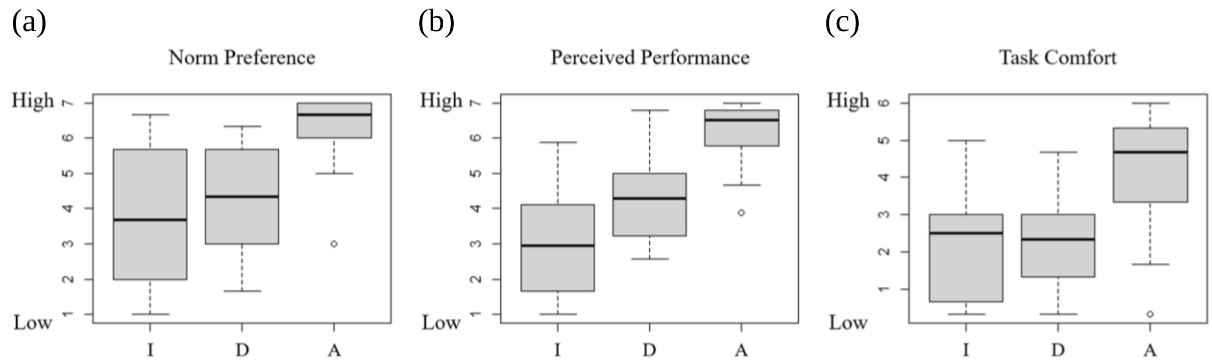


**Figure 11**

*Study III-1 cognitive consonance by reasoning norm. (a) Norm Preference. (b) Perceived Performance. (c) Task Comfort.*




### *Neural Outcomes*

For neural data, the normalized ΔHbO peak amplitude during idea generation (30s) was calculated for each channel. The peak values for the channels were then grouped by ROI. Activity in the prefrontal cortex (PFC) was higher under the abductive condition than the inductive condition, $df = 34$, $t = -2.32$, $p = .027$, with a medium-to-large effect size ($\omega^2_p = 0.11$).

Regarding the subregions of the PFC, participants showed greater HbO increase in the left VLPFC during abduction than induction, $df = 34$, $t = -2.33$, $p = .026$, $\omega^2_p = 0.11$. There was an increase in right DLPFC activation for abduction over induction, $df = 34$, $t = -2.70$, $p = .011$, with a large effect size of $\omega^2_p = 0.15$. There were no other significant results from neural data.

### *Behavioral Outcomes*

**Idea Quality**. ***Originality***. The average *originality* score was higher for ideas generated during abduction ($M = 2.73$) than induction ($M = 2.28$), $df = 34$, $t = -5.55$, $p < .001$, $\omega^2_p = 0.45$, as well as than deduction ($M = 2.49$), $df = 34$, $t = -2.93$, $p = .006$, $\omega^2_p = 0.17$, with large effect sizes. In addition, ideas generated under deduction ($M = 2.49$) were more *original* than induction ($M = 2.28$), $df = 34$, $t = -2.62$, $p = .013$, $\omega^2_p = 0.14$. ***Feasibility***. Ideas generated under abduction

(*M* = 3.63) were less *feasible* than induction (*M* = 3.89), *df* = 34, *t* = 3.27, *p* = .002, $\omega^2_p$ = 0.21. Further, ideas during deduction (*M* = 3.68) were less *feasible* than induction (*M* = 3.89), *df* = 34, *t* = -2.62, *p* = .013, $\omega^2_p$ = 0.14.

**Cognitive Dissonance**. ***Norm Preference***. Participants had more positive attitudes toward the abductive reasoning norm (*M* = 6.28) than induction (*M* = 3.70), *df* = 34, *t* = -5.55, *p* < .001, $\omega^2_p$ = 0.45, and deduction (*M* = 4.41), *df* = 34, *t* = -4.03, *p* < .001, $\omega^2_p$ = 0.30, with very large effect sizes. ***Perceived Performance***. Participants found abductive reasoning (*M* = 6.17) as more enhancing creative idea generation than induction (*M* = 3.13), *df* = 34, *t* = -8.04, *p* < .001, $\omega^2_p$ = 0.64, and deduction (*M* = 4.22), *df* = 34, *t* = -5.14, *p* < .001, $\omega^2_p$ = 0.41. They also reported their ability to generate creative ideas was more enhanced using deduction (*M* = 4.22) in comparison to induction (*M* = 3.13), *df* = 34, *t* = 2.89, *p* = .007, $\omega^2_p$ = 0.17. ***Task Comfort***. Generating creative ideas was perceived as more comfortable during abduction (*M* = 4.07) than induction (*M* = 2.35), *df* = 34, *t* = -3.82, *p* = .001, $\omega^2_p$ = 0.27, as well as compared with deduction (*M* = 2.24), *df* = 34, *t* = -4.07, *p* < .001, $\omega^2_p$ = 0.30.

There were no other significant results from behavioral data.

## Study III-1 Discussion

Neural activity in the PFC, the left VLPFC, and the right DLPFC was greater during abduction than induction with a medium-to-large or large effect sizes, though not greater than deduction. There were no differences in activity in the PFC and its subregions between induction and deduction.

Performance measured by *originality*, generally describe as a hallmark of creativity (Nijstad et al., 2010; Rietzschel et al., 2010; Stroebe et al., 2010), was the highest for abduction, while higher for deduction than induction. *Feasibility* of ideas was the lowest for abduction, and highest for induction. This was consistent with repeated findings that idea *originality* is inversely associated with *feasibility* (e.g., Goncalo & Staw, 2006; Lucas & Mai, 2022; Mueller et al., 2012), thus would not undermine our interpretation that abduction seems to best enhance creative performance.

Consistent with performance, self-reported cognitive consonance (*norm preference*, *perceived performance*, and *task comfort*) was the highest for abduction, while higher for deduction than induction (*norm preference* and perceived performance). Thus, the first hypothesis (that abduction is most favorable for creativity among the three reasoning norms) was supported by neural and behavioral data. The second hypothesis (deduction over induction) was supported only by behavioral data.

Study III-1 provides the first empirical evidence for the superiority of the abductive norm for creativity. Past-directedness embedded in inductive and deductive reasoning would have confined participants' scope of search to only what worked in the past (induction) or what must work given logical rules obtained from the past (deduction). The freedom of participants to select and retrieve information from the long-term memory would have been limited during the inductive and deductive conditions, resulting in cognitive dissonance between these norms and their beliefs about how to generate creative ideas. By contrast, abduction would have let participants actively select and retrieve from their long-term memory whichever information that they needed to be creative.

Data also imply that we may keep the millennia-old deductive reasoning in our creative skillset, which challenges the now-widely-published literature (e.g., Dunne & Martin, 2006; Habermas, 1978; Locke et al., 2008; Mantere & Ketokivi, 2013; Martin, 2009; Sætre & Van de Ven, 2021; Weick, 2005; cf. Green, 2018) suggesting that induction and deduction equally stifle creativity. That deduction allows for hypothetical reasoning, similarly to abduction, could account for our findings.

Given our findings, however, one should ask why, then, a group of researchers have recently advocated the use of inductive reasoning for creativity (Benedek, Beaty, et al., 2014; Green, 2018; Groarke, 2009; Wagner, 1996; Vartanian et al., 2003). One possible answer is that the three reasoning norms may be conceptualized and utilized differently. While we used the tightly defined, scientific versions of induction and deduction, there also exist more loosely defined, practical versions (Arthos, 2003; Kraus, 2003; McBurney, 1936). In Study III-2, we compare these different versions of reasoning under less performance pressure.

## Study III-2

Induction in the extant literature has in fact been widely implicated as enhancing creativity (e.g., Barnett & Ceci, 2002; Benedek, Beaty, et al., 2014; Green, 2018; Green et al., 2008, 2010, 2012; Groarke, 2009; Holyoak, 2012; Holyoak & Thagard, 1995; Wagner, 1996; Vartanian et al., 2003). On the surface, that inductive reasoning *can* be creative seems to directly contradict findings from Study III-1. However, there are at least two notable differences between Study III-1 and these studies. First, Study III-1 operationalized the tight version of induction, whereas prior research on inductive reasoning and creativity has mostly used a loose form of induction, “analogical reasoning.” It was inductive reasoning specifically in the form of analogy that has been associated with increased activity in brain regions involved in creative cognition (e.g., the frontopolar cortex, the left DMPFC, Benedek, Beaty, et al., 2014; Green et al., 2006, 2012) and enhanced creative performance (e.g., integrating distant information, fluency, art, and science, Green et al., 2012; Groarke, 2009; Holyoak & Thagard, 1995; Smith & Ward, 2012; Vartanian et al., 2003). The creative potential of analogical reasoning (and induction, in more general) is due to it, though drawing on past data, leading to information beyond what is strictly known from the past (Groarke, 2009; Klix, 2001; Wagner, 1996). For example, “Feature phones by Motorola, Blackberry, and so on, all sold well” was “known” which led to an “unknown,” which was “If a phone is a feature phone, it sells well.” Although this was an uncreative example from Study III-1, drawing unknown conclusions *can* be creative. Take this new example of (inductive) analogical reasoning, “I have used a laptop connected to the mobile internet, which I loved (known); so, people will love a cellphone that can do the same (unknown).” According to Green (2018), what has been unknown heretofore is novel to some degree (and novelty is central to creativity as we discussed), which explains why analogical reasoning can be creative. The tight version of induction in Study III-1 had asked participants to generate ideas based on many repeated past cases with identical objects. By contrast, the defining characteristic of analogical reasoning is as simple as any property shared between two objects (Holyoak, 2005; Tversky, 1977), such as the portable internet access for both a laptop (source analog) and a cellphone (target analog) in our new example. Only one (or more) available past case with varying degrees of similarity suffice for (inductive) analogical reasoning (Green, 2018).

Secondly, Study III-1 imposed moderately strong pressures to strictly adhere to the given reasoning type and to solely generate highly creative ideas to avoid penalty. These emphases in Study III-1 reflected the organizational context, where pressures toward adherence to a mode of reasoning and expectations of high-quality contributions are taken for granted (Dunne & Martin, 2006; Weick, 2005; see Baer & Frese, 2003; Edmondson, 1999). Such pressures were absent in research on analogical reasoning. This seems consistent with the non-organizational contexts of previous studies on analogical reasoning.

In sum, previous findings on analogical reasoning speak for the creativity of induction (e.g., Benedek, Beaty et al., 2014; Green et al., 2006, 2012; Vartanian et al., 2003). Furthermore, induction, as much as deduction, is one of the mostly widely acknowledged reasoning types (Dunne & Martin, 2006; Joullié, 2016; Sætre & Van de Ven, 2021). Thus, we should carefully avoid overgeneralizing from Study III-1 that induction is least conducive to creativity. Study III-2 tests how induction in its loose form of analogical reasoning compare with deduction and abduction.

## Research Questions

Study III-2 compares the effectiveness of loose forms of reasoning for creative cognition (activity in the PFC and its subregions), performance (idea quality), and experience (cognitive dissonance/consonance), the same dependent variables as in Study III-1. Due to the informality of the loose versions of induction and deduction, the barriers to creativity stemming from formal logical demands as in Study III-1 may disappear. However, we investigate these effects as open-ended research questions rather than as hypotheses, given there is evidence in support of creativity of (inductive) analogical reasoning (e.g., Benedek et al., 2014; Green et al., 2006, 2012; Vartanian et al., 2003) as well as deduction and abduction (Study III-1).

## Method

### *Participants*

All 18 participants were undergraduate and graduate, right-handed, Korean-speaking students at a university in Korea. They participated for a monetary compensation. The study was approved by the university IRB. This sample was selected for two reasons. First, we tried to diversify research populations by studying both the Asian (Korean) sample, who are underrepresented in neuroscience research, and the western (American) sample (regarding racial/ethnic representation in neuroimaging, see Buchanan et al., 2021; Dotson & Duarte, 2020; Li et al., 2022; Syed et al., 2018). Second, due to the COVID-19, we were unable to collect data in the United States for a year, and the third and sixth authors provided an opportunity to collect data in Korea. On the one hand, there have been no definitive findings on the Asian-western differences regarding creative ability (Sawyer, 2012; Shao et al., 2019; Westwood & Low, 2003; Xie & Paik, 2018). On the other hand, there has been evidence that American and Korean lay conceptions of creativity largely overlap (Lim & Plucker, 2001). Further, variables potentially relevant for western-Asian creativity differences such as individual-collectivist values, innovative-adaptive styles, freedom to express, power distance, or uncertainty avoidance (Kim, 2009, 2011; Xie & Paik, 2018) are not the focal variables in Studies III-1 and III-2. Thus, we do not expect racial/ethnic diversity in our samples to affect creativity in relation to reasoning norms.

Study III-2 involved the same three—analogical (inductive), deductive, and abductive—within-subject reasoning conditions, repeated measures, and task repetition (45 trials per participant, 15 trials x 3 conditions) as in Study III-1. Study III-2 was sufficiently powered with 18 participants to detect small effects.

***Procedures***

The instructions for induction in Study III-2 will ask participants to generate ideas based on any “similar past experience.” For a comparable test, we also use a loose form of deduction. Loose deduction asks participants to generate creative ideas based simply on a “common” characteristic of the given object, instead of a “universal” characteristic as in Study III-1. The instruction for abductive reasoning will not change, because abduction is inherently loose in form (Fann, 1970; Hoffmann, 1999; Shepherd & Sutcliffe, 2011). In addition, the emphases on formality and performance for credit as in Study III-1 were absent. Instructions were in Korean.

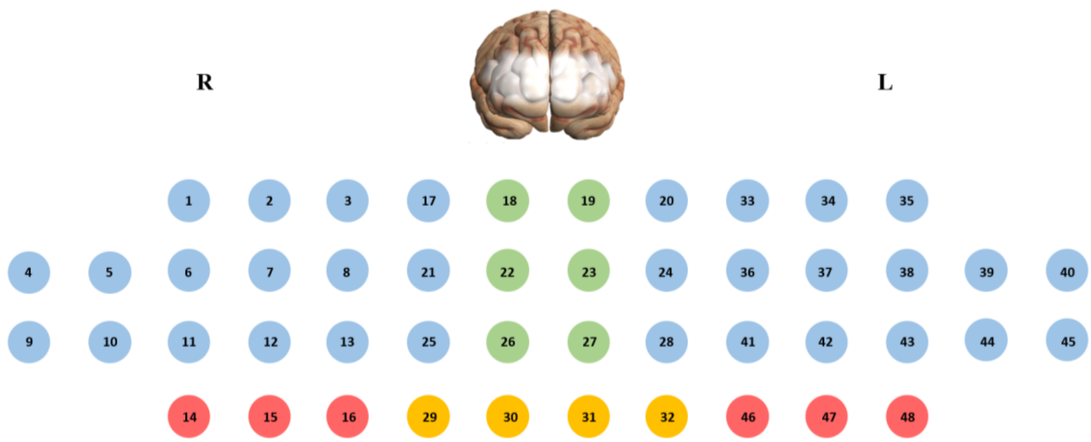
**Behavioral Measures.** ***Quality of Ideas.*** The same three independent trained raters as Study III-1, blind to condition, coded one third of 1,717 ideas participants generated for *originality* and *feasibility* on a *1* (*lowest*) to *5* (*highest*) scale. ***Cognitive Dissonance.*** *Norm preference* (3 items for each of induction, deduction, and abduction, Cronbach's $\alpha$ = .68, .90, and .84, respectively), *perceived performance* (9 items each, Cronbach's $\alpha$ = .72, .72, and .81, respectively), and *task comfort* (3 items each, Cronbach's $\alpha$ = .53, .68, and .75, respectively) were measured on a Likert scale of *1* (*strongly disagree*) to *7* (*strongly agree*).

**fNIRS Recording and Signal Processing**

The neural data in Study III-2 were acquired using a wearable fNIRS device (NIRSIT, OBELAB Inc.) placed on the forehead. The data were collected at 780 and 850 nm wavelengths at a sampling rate of 3.906 Hz with 24 emitters and 32 detectors. A total of 48 channels covered most of the PFC. Based on Gozzi et al. (2009), the following channels have been acquired: Channels 46/47/48 and channels 14/15/16 correspond to the left and right VLPFC (BA 45/47); channels 31/32 and channels 29/30 to the left and right VMPFC (BA 10); channels 20/24/28/33-45 and channels 1-13/17/21/25 to the left and right DLPFC (BA 9/46); and channels 19/23/27 and channels 18/22/26 to the left and right DMPFC (BA 8/9).

**Figure 12**

*Study III-2 fNIRS channel locations of the PFC subareas—the bilateral VLPFC (red), VMPFC (yellow), DLPFC (blue), and DMPFC (green) using NIRSIT.*




## Results

Significant findings are reported using pairwise contrasts for neural and behavioral outcomes. Since we were interested in exploring the differences across the three reasoning types, subsequent Tukey-adjusted post-hoc pairwise contrasts were performed to account for the increased familywise Type I error rate due to multiple comparisons.

**Table 19**

*Study III-2 ROI configuration of prefrontal subareas using NIRSIT based on Gozzi et al. (2009)*

| ROI (Brodmann Area) / MNI coordinates | | | Channels with approx. MNI coordinates | | | |
|---|---|---|---|---|---|---|
| | | | # | x | y | z |
| VLPFC (45, 47) | Left | $x < -20$ | 46 | -27 | 67 | -10 |
| | | $z \leq 1$ | 47 | -38 | 61 | -10 |
| | | | 48 | -48 | 49 | -11 |
| | Right | $x > 20$ | 14 | 50 | 51 | -8 |
| | | $z \leq 1$ | 15 | 43 | 61 | -8 |
| | | | 16 | 34 | 67 | -8 |
| VMPFC (10) | Left | $-20 \leq x < 0$ | 31 | -2 | 70 | -8 |
| | | $z \leq 1$ | 32 | -15 | 71 | -9 |
| | Right | $0 \leq x \leq 20$ | 29 | 22 | 71 | -7 |
| | | $z \leq 1$ | 30 | 11 | 73 | -8 |

| | | | | | | |
|---|---|---|---|---|---|---|
| DLPFC (9, 46) | Left | $x < -10$<br>$z > 1$ | 20 | -14 | 63 | 33 |
| | | | 24 | -15 | 70 | 19 |
| | | | 28 | -15 | 73 | 5 |
| | | | 33 | -26 | 57 | 32 |
| | | | 34 | -38 | 49 | 32 |
| | | | 35 | -47 | 38 | 32 |
| | | | 36 | -27 | 65 | 20 |
| | | | 37 | -38 | 58 | 20 |
| | | | 38 | -48 | 45 | 20 |
| | | | 39 | -55 | 32 | 18 |
| | | | 40 | -60 | 19 | 19 |
| | | | 41 | -27 | 68 | 4 |
| | | | 42 | -39 | 62 | 4 |
| | | | 43 | -48 | 50 | 4 |
| | | | 44 | -55 | 37 | 4 |
| | | | 45 | -58 | 24 | 5 |
| | Right | $x > 10$<br>$z > 1$ | 1 | 48 | 38 | 33 |
| | | | 2 | 40 | 48 | 32 |
| | | | 3 | 32 | 56 | 32 |
| | | | 4 | 61 | 23 | 21 |
| | | | 5 | 57 | 34 | 21 |
| | | | 6 | 50 | 46 | 21 |
| | | | 7 | 42 | 56 | 20 |
| | | | 8 | 34 | 63 | 19 |
| | | | 9 | 60 | 28 | 7 |
| | | | 10 | 57 | 38 | 6 |
| | | | 11 | 50 | 51 | 6 |
| | | | 12 | 44 | 60 | 6 |
| | | | 13 | 33 | 67 | 6 |
| | | | 17 | 21 | 62 | 32 |
| | | | 21 | 22 | 70 | 19 |
| | | | 25 | 22 | 72 | 6 |
| DMPFC (8, 9) | Left | $-10 \leq x < 0$<br>$z > 1$ | 19 | -2 | 63 | 32 |
| | | | 23 | -3 | 69 | 18 |
| | | | 27 | -4 | 71 | 5 |
| | Right | $0 \leq x \leq 10$<br>$z > 1$ | 18 | 11 | 65 | 32 |
| | | | 22 | 12 | 71 | 19 |
| | | | 26 | 12 | 74 | 6 |

**Table 20**

*Study III-2 mean (SD) and pairwise comparisons of neural outcomes (N = 18)*

| | | Comparisons | | $t$ | $p$ (Tukey) | $\omega^2_p$ |
|---|---|---|---|---|---|---|
| PFC | I | | D | 0.04 | .970 | - |
| | I | | A | 1.26 | .215 | - |
| | D | | A | 1.23 | .229 | - |
| Subregions | | | | | | |
| Left VLPFC | I | | D | 1.64 | .111 | - |
| | I | > | A | 2.08 | .045 (.110) † | - |
| | D | | A | 0.45 | .659 | - |
| Right VLPFC | I | | D | -1.31 | .201 | - |
| | I | | A | -0.08 | .939 | - |
| | D | | A | 1.23 | .228 | - |
| Left VMPFC | I | | D | 0.30 | .768 | - |
| | I | | A | 0.65 | .519 | - |
| | D | | A | 0.36 | .725 | - |
| Right VMPFC | I | | D | 1.15 | .262 | - |
| | I | | A | 0.92 | .365 | - |
| | D | | A | -0.23 | .823 | - |
| Left DLPFC | I | | D | -0.39 | .698 | - |
| | I | | A | 0.53 | .602 | - |
| | D | | A | 0.94 | .357 | - |
| Right DLPFC | I | | D | -1.03 | .310 | - |
| | I | | A | 0.10 | .922 | - |
| | D | | A | 1.13 | .267 | - |
| Left DMPFC | I | > | D | 2.50 | .020 (.052) † | - |
| | I | | A | 1.19 | .242 | - |
| | D | | A | -1.26 | .219 | - |
| Right DMPFC | I | | D | 0.81 | .429 | - |
| | I | | A | 0.09 | .928 | - |
| | D | | A | -0.72 | .483 | - |

*Note.* † $p > .05$ when Tukey-adjusted.

**Table 21**

*Study III-2 mean (SD) and pairwise comparisons of neural outcomes (N = 18)*

| | Comparisons | | | *t* | *p (Tukey)* | $\omega^2_p$ |
|---|---|---|---|---|---|---|
| MPFC | **I** | > | D | 2.51 | .017 (.043)* | 0.13 |
| | I | | A | 1.33 | .191 | - |
| | D | | A | -1.18 | .246 | - |

*Note.* * *p* < .05 after Tukey adjustment. Bold font indicates greater than the compared reasoning norm.

**Table 22**

*Study III-2 mean (SD) and pairwise comparisons of behavioral outcomes (N = 18)*

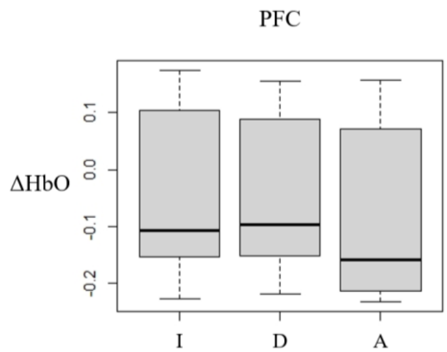
| | Comparisons | | | *t* | *p (Tukey)* | $\omega^2_p$ | Mean (*SD*) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | I | D | A |
| Idea quality | | | | | | | | | |
| *Originality* | I | | D | -1.47 | .151 | - | 2.55 *(0.22)* | 2.64 *(0.23)* | - |
| | I | | A | -0.75 | .460 | - | 2.55 *(0.22)* | - | 2.60 *(0.29)* |
| | D | | A | 0.72 | .475 | - | - | 2.64 *(0.23)* | 2.60 *(0.29)* |
| *Feasibility* | **I** | > | D | 2.42 | .019 (.049)* | 0.12 | **4.06 *(0.36)*** | 3.83 *(0.36)* | - |
| | I | | A | -0.96 | .344 | - | 4.06 *(0.36)* | - | 4.16 *(0.26)* |
| | D | < | **A** | -3.42 | .002 (.005)* | 0.23 | - | 3.83 *(0.36)* | **4.16 *(0.26)*** |
| Consonance | | | | | | | | | |
| *Norm Preference* | I | < | **D** | -2.52 | .015 (.043)* | 0.09 | 4.46 *(1.06)* | **5.45 *(1.10)*** | - |
| | I | | A | 0.04 | .965 | - | 4.46 *(1.06)* | - | 4.45 *(1.24)* |
| | **D** | > | A | 2.57 | .013 (.039)* | 0.10 | - | **5.45 *(1.10)*** | 4.45 *(1.24)* |
| *Perceived Performance* | I | < | **D** | 3.14 | .003 (.009)** | 0.14 | 4.07 *(0.77)* | **4.91 *(0.67)*** | - |
| | I | | A | -2.01 | .050 (.125) | - | 4.07 *(0.77)* | - | 4.60 *(0.88)* |
| | D | | A | 1.13 | .263 | - | - | 4.91 *(0.67)* | 4.60 *(0.88)* |
| *Task Comfort* | I | | D | 0.33 | .742 | - | 3.89 *(1.04)* | 3.98 *(1.13)* | - |
| | I | < | **A** | -3.64 | .001 (.003)** | 0.25 | 3.89 *(1.04)* | - | **4.91 *(1.20)*** |
| | D | < | **A** | -3.31 | .002 (.006)** | 0.22 | - | 3.98 *(1.13)* | **4.91 *(1.20)*** |

*Note*. Both * *p* < .05 and ** *p* < .01 after Tukey adjustment. Bold font indicates significantly greater than the compared reasoning norm.

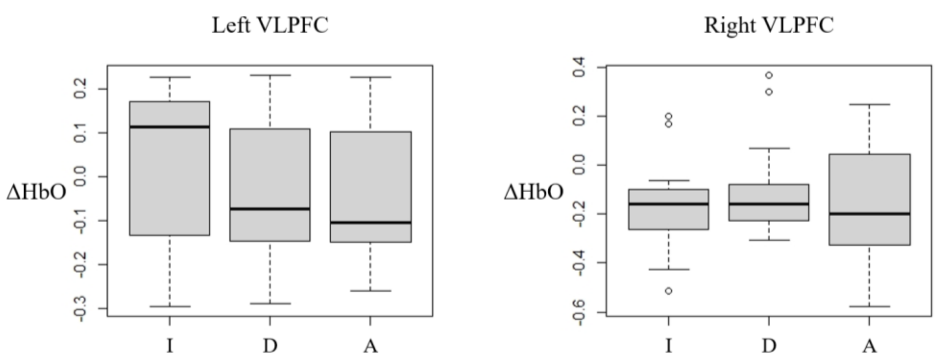
**Figure 13**

*Study III-2 activity in the PFC and its subareas by reasoning norm. (a) PFC. (b) VLPFC. (c) VMPFC. (d) DLPFC. (e) DMPFC. (f) MPFC.*

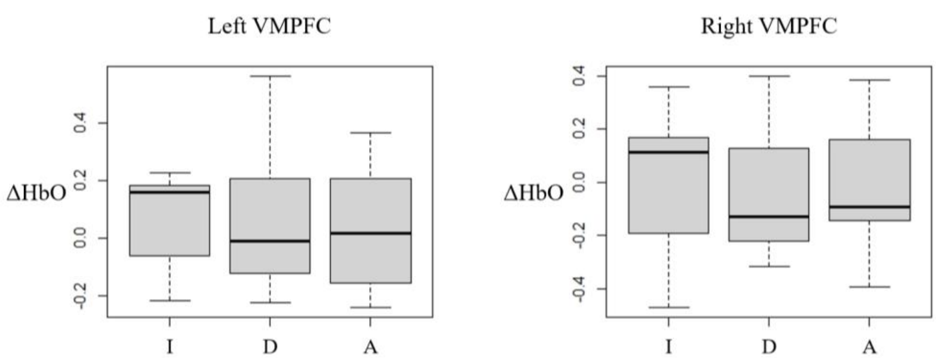
(a)



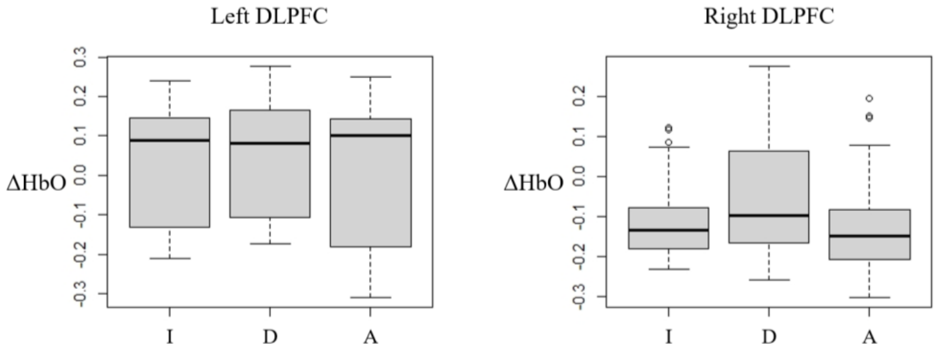

(b)



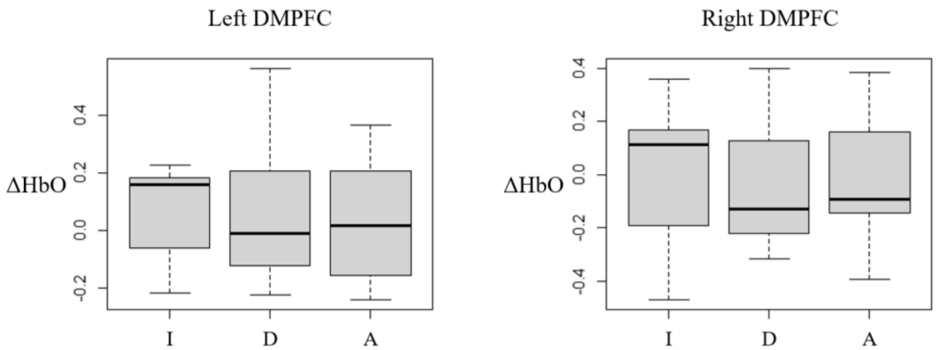

(c)



(d)


Left DLPFC
Right DLPFC
ΔHbO
ΔHbO
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
I
D
A

(e)


Left DMPFC
Right DMPFC
ΔHbO
ΔHbO
0.4
0.2
0.0
-0.2
-0.4
I
D
A

(f)

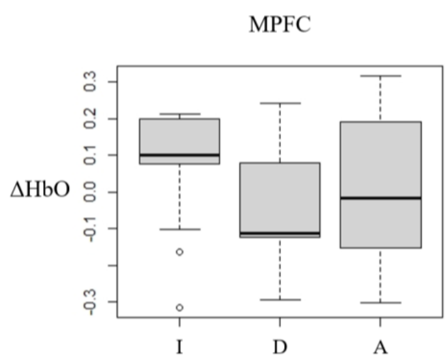

MPFC
ΔHbO
0.3
0.2
0.1
0.0
-0.1
-0.3
I
D
A

**Figure 14**

*Study III-2 idea quality by reasoning norm. (a) originality. (b) feasibility.*

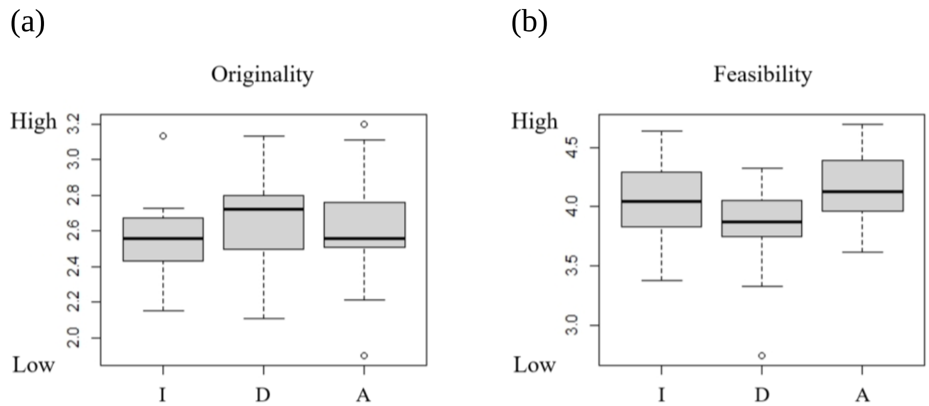
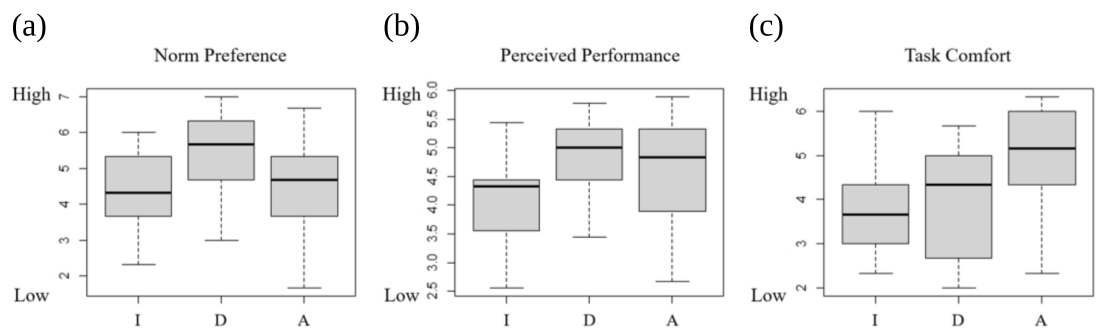



**Figure 15**

*Study III-2 cognitive consonance by reasoning norm. (a) Norm Preference. (b) Perceived Performance. (c) Task Comfort.*




***Neural Outcomes***. Participants showed a lower HbO increase in the left VLPFC during abduction (*M* = -0.0377) than induction (*M* = 0.0365), *df* = 32, *t* = -2.08, *p* = .045. However, after the Tukey adjustment, this difference was not significant at *p* = .110. Activity in the left DMPFC during induction (*M* = 0.1153) was greater than during deduction (M = -0.0181), *df* = 30, *t* = 2.45, *p* = .020, but the difference was only marginally significant when Tukey-adjusted, *p* = .052. A post-hoc analysis revealed that activity in the medial prefrontal cortices (MPFC; channels 18, 19, 22, 23, 26, 27, 29, 30, 31, and 32) associated with generating creative metaphors (Benedek, Beaty, et al., 2014) was higher during induction (*M* = 0.07943) than deduction (*M* = -0.05238), *df* = 34, *t* = 2.51, *p* = .017, $\omega^2_p$ = 0.13. This effect remained significant after the Tukey adjustment, *p* = .043. No other reasoning effects in the PFC and its subregions were statistically significant.

### ***Behavioral Outcomes***

**Idea Quality**. ***Originality***. No differences in *originality* were found across conditions. ***Feasibility***. Ideas generated under abduction (*M* = 4.16) were more *feasible* than deduction (*M* = 3.83), *df* = 34, *t* = -3.42, *p* = .002, $\omega^2_p$ = 0.23, which were significant after Tukey correction, *p* = .005. Further, ideas during deduction (*M* = 3.83) were less *feasible* than induction (*M* = 4.06), *df* = 34, *t* = -2.46, *p* = .019, $\omega^2_p$ = 0.12, remaining significant after Tukey's adjustment, *p* = .049.

**Cognitive Dissonance**. ***Norm Preference***. Participants showed a more positive attitude toward deductive reasoning (*M* = 5.45) than abduction (*M* = 4.45), *df* = 51, *t* = 2.57, *p* = .013, $\omega^2_p$ = 0.10, remaining significant after Tukey adjustment, *p* = .039. Participants showed a more positive attitude toward deduction (*M* = 5.45) than induction (*M* = 4.46), *df* = 51, *t* = 2.52, *p* = .015, $\omega^2_p$ = 0.09, and *p* = .043 after Tukey correction. ***Perceived Performance***. Participants found abductive reasoning (*M* = 4.60) as more enhancing creative idea generation than induction (*M* = 4.07), *df* = 51, *t* = 2.01, *p* = .050, $\omega^2_p$ = 0.05, but *p* = .125 when Tukey-adjusted. Participants' self-reported ability to generate creative ideas was more enhanced using deduction (*M* = 4.91) in comparison to induction (*M* = 4.07), *df* = 51, *t* = 3.14, *p* = .003, $\omega^2_p$ = 0.14, and *p* = .009 when Tukey-corrected. ***Task Comfort***. Generating creative ideas was perceived as more comfortable during abduction (*M* = 4.91) than induction (*M* = 3.89), *df* = 34, *t* = -3.64, *p* = .001, $\omega^2_p$ = 0.25 (*p* = .003; Tukey-corrected), as well as than deduction (*M* = 3.98), *df* = 34, *t* = -3.31, *p* = .002, $\omega^2_p$ = 0.22 (*p* = .006; Tukey-corrected).

There were no other significant results from behavioral data.

**Study III-2 Discussion**

Neural activity in a priori ROIs associated with creative cognition (the PFC and its subregions) exhibited no difference across conditions. Post hoc analysis with Tukey adjustment showed higher activity in the MPFC during induction than deduction. This finding is consistent with the conceptualization of induction as analogical reasoning, because the MPFC has been found to be associated with the generation of creative metaphors (Benedek, Beaty, et al., 2014).

Performance in terms of *originality* similarly showed no difference by condition. *Feasibility*, which is often weakly or inversely correlated with originality (Goncalo & Staw, 2006; Mueller et al., 2012), was the highest under abduction, and lowest under deduction. This result is not subject to straightforward interpretation, but opens the possibility that loose applications of induction and deduction may in fact be more compatible with creative idea generation than abduction.

Self-reported cognitive consonance measures were higher for deduction than abduction and induction on *norm preference* and *perceived performance*, while higher for abduction than induction and deduction on *task comfort*. Taken together with the neural and performance results, participants' beliefs about creativity may still be more coherent with deduction and abduction than analogical reasoning (induction), while the latter is comparable to the former two in its usefulness for creativity.

Study III-2 results show that superiority of abduction and deduction over induction for creativity that was found consistently from neural and behavioral measures in Study III-1 disappear when induction is conceptualized as analogical reasoning and the performance pressure was lower than in Study III-1. Though more research is needed, Study III-2 helps make sense of studies that endorse the usefulness of induction for creativity (Benedek, Beaty, et al., 2014; Green, 2018; Green et al., 2008, 2010, 2012; Holyoak & Morrison, 2012; Holyoak & Thagard, 1995; Wagner, 1996; Vartanian et al., 2003).

## General Discussion

Three questions motivated this research. First, that inductive and deductive norms should be replaced or supplemented with an abductive norm to be creative (e.g., Dunne & Dougherty, 2016; Dunne & Martin, 2006; Liedtka, 2004; Locke et al., 2008; Mantere & Ketokivi, 2013; Martin, 2009; Roozenburg, 1993; Roozenburg & Eekels, 1995; Sætre & Van de Ven, 2021; Weick, 2005) has been untested. This is an important topic to pursue because the former two have since Aristotle been arguably the most widely acknowledged (see Johnson-Laird, 2015; McBurney, 1936; Skinner, 1984; Weick, 2005) and are norms in education and organizations that are currently predominant to the point that abduction is ignored (Dunne & Martin, 2006; Martin, 2009; Weick, 2005). Peirce (1955, 1998) explains why induction and deduction are commonly incapable of creating new information: Both are past-based, while induction repeats the past and deduction systematically reaches obvious conclusions (Dunne & Martin, 2006; Martin, 2009). Neither seems to introduce new information. Consequently, the usefulness of abductive reasoning in creativity over and above induction and deduction was a closed debate to Peirce, and scholars today generally seem to agree (e.g., Cross, 1990; Dunne & Martin, 2006; Habermas, 1978; Liedtka, 2004; Martin, 2009; Roozenburg, 1993; Roozenburg & Eekels, 1995; Sætre & Van de Ven, 2021; Weick, 2005). However, as we import these competing concepts from the field of logic into human experience of norms, the emphases shift from logical necessity to probability (Dewey, 1920; Kraus, 2003; McBurney, 1936), and the case is still open for empirical testing. Second and relatedly, the less direct but implied claim that induction and deduction are equally against creativity (Dunne & Martin, 2006; Locke et al., 2008; Martin, 2009; Sætre & Van de Ven, 2021; Weick, 2005) demanded investigation. Deduction could take hypothetical (if-then) forms (Hoffmann, 1999; Johnson-Laird, 1995; Johnson-Laird et al., 1992;), and also expose connections that are obvious but hidden to our consciousness (Morris, 1992; Wagner, 1996). Thus, deduction might be more consistent with creative thinking than induction (Galle, 1996; Wagner, 1996), though not on a par with abduction due to its rigid reasoning structure. Third, there exist two seemingly contradictory views in the literature on the value of induction for creativity, which called for explanation. The positive side (e.g., Benedek, Beaty, et al., 2014; Green, 2018; Holyoak & Morrison, 2012) finds the creative potential of analogical reasoning, which they refer to synonymously with induction, from it leading to novel information rooted in but beyond what is known from the past (Groarke, 2009; Klix, 2001; Wagner, 1996).

Study III-1 with American participants attempted to address the first two empirical questions by using tightly defined induction and deduction with some performance pressure in order to operationalize organizational dynamics. Participants in an fNIRS laboratory were asked to think of creative alternative uses for everyday objects under each reasoning norm. We found the superiority of abduction for creative idea generation over the other two with neural (activity in the PFC, the left VLPFC, and the right DLPFC) and behavioral data (*originality* and cognitive consonance in terms of *norm preference*, *perceived performance*, and *task comfort*), and deduction over induction (*originality* and *perceived performance*). On the one hand, this is consistent with the mainstream view that abduction is the best path among the three to creativity, while on the other undermining the view that it is the exclusive path.

Study III-2 with Korean participants was intended to explore the third question by using the same study design but involving loose forms of induction (analogical reasoning based simply on similarity) and deduction (without requiring the universality of characteristics) and, for consistency with previous research on analogical reasoning (e.g., Benedek, Beaty, et al., 2014; Green et al., 2006, 2012; Vartanian et al., 2003), with less performance pressure. Both neural (activity in the PFC and its subregions) and behavioral (idea quality and survey measures on cognitive consonance) data suggest that the relative advantages of abduction and deduction over induction (analogical reasoning) seem to disappear. The only statistically significant findings after adjusting for multiple comparisons were that deduction was associated with higher *norm preference* and *perceived performance*, and abduction with higher *task comfort*, while activity in the MPFC, a region associated with generating creative metaphors (Benedek, Beaty, et al., 2014), was higher during induction than deduction. Taken together, Study III-1 and Study III-2 provide evidence for both the negative and positive views, respectively, on induction in creativity. By understanding that there are at least two—tight and loose—kinds of induction, we can reconcile both views and integrate them into a coherent theory of creative reasoning types.

Of note, we do not conclude that any reasoning "type" per se was directly tested. Instead, what has been tested is the reasoning types that were imposed as norms to be followed. We put forward three reasons on this point. One, it is difficult to manipulate how one actually thinks. Asking participants to think in one way does not necessarily make them think in that way. We only have some evidence from the manipulation check, training session, and survey responses indicating participants did understand the specific reasoning requirements and tried to follow through. Two, all three types of reasoning are co-present in actual creative reasoning (Roozenburg, 1993; Roozenburg & Eekels, 1995). For example, even in the generation of the abductively derived idea "People will love smartphone," there likely have been a quick processing of past experiences (induction) that bear similarities with the presumed smartphone features such as mobile internet, a portable television, a wireless computer, or a touch screen and to logical rules (deduction) such as “All people want mobile internet”. Three, the alternative uses task itself forces abductive reasoning to a degree, because thinking of creative uses for everyday objects entails guessing a possibility based on incomplete information. So, even under the inductive and deductive conditions, participants’ thought must have involved some abductive reasoning.

The current research also examined only the divergent creativity and referred to creative idea generation as creativity for simplicity purposes. Creativity comprises at least two temporal components—first the divergent thinking phase when choices are created and then the convergent thinking phase where choices are made (Girotra et al., 2010; Paulus et al., 2019). Thus, we avoid generalizing our findings to the entire creative processes, particularly the convergent stage. Induction and deduction would have more roles to play during the convergent phase of creative process, as discussed in the introduction of this study (see also Dunne & Martin, 2006; Martin, 2009; Cramer-Petersen et al., 2019; Dong et al., 2015).

**Limitations**

There are several limitations in this study. First, all participants in Study III-1 and Study III-2 had a STEM background, so our findings may not generalize to people with different training or cognitive styles. During our pilot study, we observed a few participants with a humanities or social sciences background who reported having the most difficulties with thinking abductively. These participants said in debriefings that the abductive (“possibility”) condition offered them too much freedom that they were too overwhelmed, rather than encouraged, to think creatively. It may be that they could not readily identify from the everyday physical objects some mental anchors or constraints—as well as the STEM participants did—that are needed for creative thinking (on the relationship between constraints and creativity, see Acar et al., 2019; Klein, 2013). It seems possible that humanities or social sciences majors would find abduction favorable to creative thinking if the objects to generate ideas about are, for example, social concepts instead of physical objects.

Second, though unlikely, there may have been unknown cultural differences between the American (Study III-1) and Korean (Study III-2) participants that affected their creative cognition or behavioral responses. The difference in nationality and culture also creates a difficulty in comparing outcomes across Study III-1 and Study III-2.

Third, our research involved separate individuals than groups or teams. Our focal variable, reasoning types, was largely inspired by their social and organizational aspects and was conceptualized as norms, which is more commonly defined in social than individual terms. Future research can use hyperscanning of two or more individuals brainstorming together to test the external validity of our findings. Relatedly, the findings will be more generalizable with professionals from organizations, instead of undergraduate and graduate students, as participants.

Fourth, due to the limited number of optodes and the limited spatial resolution, most fNIRS studies including ours can access only part of the cerebral cortex. In Study III-1 and Study III-2, the optodes covered the entire PFC, while the remaining brain regions had to be left out. The inferior parietal cortex (IPC) associated with retrieving past memory (Fink et al., 2010; Schacter et al., 2012) and temporo-parietal junction (TPJ) associated with cognitive conflict (Qin et al., 2011), and the greater portion of the VMPFC associated with combination of distant information could have responded differently to each reasoning norm, for example, had we been able to detect neural signals from those regions using functional magnetic resonance imaging (fMRI). More importantly, fNIRS can only collect cortical signals within 15~25 mm beneath the scalp. Thus, brain regions such as the amygdala, the insula, and the cingulate cortex that are key to understanding affective and reward processing (Liu et al., 2011; Peters & Büchel, 2010) are inaccessible for fNIRS. As induction and deduction in Study III-1 were found as relatively troubling for participants during the alternatives uses task, an fMRI study will be able to test if the amygdala (often associated with negative emotions) will show greater activation under induction and deduction than abduction.

Lastly, the versions of the three reasoning norms used in our two studies are by no means exhaustive. These norms may still be defined in different ways and result in different outcomes.

**Conclusion**

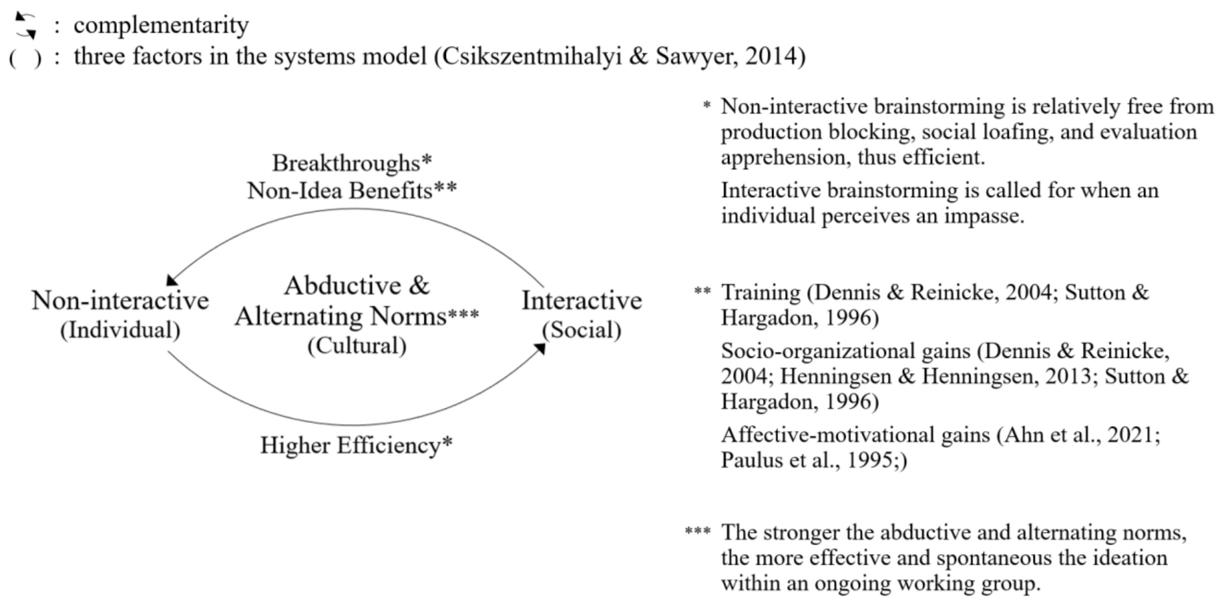
Study III reports the first controlled experiments on the effects of inductive, deductive, and abductive reasoning norms on divergent creativity. Neural and behavioral data suggest that each norm has creative potential: With tight definitions of the reasoning norms under a moderately high performance pressure, abduction was most and deduction second-most compatible with creative idea generation, and the differences largely disappeared when using loosely defined reasoning norms with less pressure to perform. Regarding creativity, our results are consistent with the widely claimed superiority of abductive reasoning, challenges the literature on the usefulness of deductive reasoning, and reconciles two seemingly contradictory views on the value of inductive reasoning. Further research to replicate these findings using different reasoning versions and creative tasks is necessary.

## Conclusion: Towards a Systems Model of Ideation

The relationships among individual, social, and cultural factors for ideation (i.e., generation and selection of ideas) in the three studies are captured in the systems approach (see Csikszentmihalyi, 1997). Communicating (or "hybrid") groups in Studies I and II reflect the social factors. These social factors are complementary with (rather than substitutive of) noninteractive individuals, which represents the individual factor. Thus, it is more of a false dilemma to consider abandoning one mode of idea generation (communicating groups) in favor of the other (noncommunicating individuals). In addition, generating and communicating creative ideas under the abductive norm of reasoning in Study III-1 matches the cultural (organizational) factor. Given the distinctive benefits from all—individual, group, and cultural—factors, a systems model of ideation is proposed below. In doing so, the discussion in Study I on the importance of alternation between noninteractive (noncommunicating) and interactive (communicating) sessions is primarily revisited.

The integrative model outlined below explicates a loop of noninteractive and interactive ideation (of the individual and social factors, respectively), where the interdependence relies on the shared norm (of the cultural factor) to encourage abductive reasoning and generate ideas together when asked for. These collective efforts are embedded in the long-term nonlinear path to innovation as idea generation and selection are repeated both at the individual and group levels (see Leonard & Sensiper, 1998). As in the original systems model of creativity by Csikszentmihalyi (1997), selectively acknowledging high-quality ideas is an essential function of the social factor (interactive groups), because it seems obvious that selection of ideas to build upon and implement should be done in a group of responsible individuals than by a single individual in most real-world scenarios. The relationships among the three factors are visualized in Figure 16.

**Figure 16**
*A systems model of ideation.*




### *Individual-Cognitive Factors*

The systems model of ideation ("systems model" hereafter) conceptualizes the relatively higher efficiency of noninteractive (individual) idea generation—due to the absence of production blocking, evaluation apprehension, and social loafing (for review see Stroebe et al., 2010)—as stimulating idea generation during the following interactive phase. This is because individually generated ideas presented in a group can cause an upward spiral of creative attempts in that group (Korde & Paulus, 2017; Lu et al., 2018).

In addition, knowing the fact that they will share ideas to the group, individual members would pre-evaluate their own ideas before sharing and, at least roughly, decide the order by which to present their ideas (as implied in Study II). This voluntary pre-evaluation explanation is consistent with the reported tendency for "status auction" during interactive ideation among professionals as they want to be seen as capable in creative problem solving to their clients, colleagues, and to the leadership in their organizations (Sutton & Hargadon, 1996). Such pre-evaluation would increase individuals' ability to assess ideas as well as the effectiveness of group discussion during a subsequent idea selection phase, especially if the criteria to evaluate have been clearly communicated (Ahn et al., 2022; Rietzschel et al., 2010, 2014).

***Social-Affective Factors***

The relative strengths of group ideation are that it (1) can provide breakthrough ideas when individuals have already done an exhaustive search on their own, (2) enables novel syntheses of ideas from individuals with different experience, training, and cognitive styles (Fink et al., 2010; Koestler, 1964; Korde & Paulus, 2017), (3) provides opportunities for recognition and career development (e.g., training, networking, Dennis & Reinicke, 2004; skill variety, Sutton & Hargadon, 1996), (4) enables organization building (e.g., cohesiveness, Henningsen & Henningsen, 2013; status auction, organizational memory, creative norms, Sutton & Hargadon, 1996), (5) increases satisfaction (e.g., well-being, social support, Dennis & Reinicke, 2004; equitable decision making, Kramer et al., 1997), (6) increases motivation (e.g., goal clarity, engagement, task attractiveness, Ahn et al., 2022), and (7) can facilitate decision making, particularly when given specific creative criteria (Ahn et al., 2022; Rietzschel et al., 2010, 2014).

***Cultural-Normative Factors***

The shared cultural (organizational) norms to encourage abductive reasoning (as in Study III-1) and to co-create in a nonlinear way would sustain the social and individual factors in a mutually beneficial relationship. The stronger these shared norms, the more enhanced the effectiveness of each session and the easier the repeated alternation between individual and group ideation, until the desired outcomes are achieved. For example, a group or team can effectively motivate and cognitively stimulate individual members, who are, when at an impasse, encouraged by the organizational norm to spontaneously ask for ideation meetings in order to get "unstuck" (Sutton & Hargadon, 1996, p. 703-704). This view is also consistent with reports that individual ideation, alternating with group ideation, is woven "into the cultural fabric" (Amabile et al., 2014; Kelley, 2001, p. 55) at innovative organizations that promote abductive reasoning. In this innovative culture, risk-taking based on abductive reasoning and collaborative generosity are the norms (Hargadon & Bechky, 2006; Sutton & Hargadon, 1996). So, members can have a strong conviction that they will be allowed to generate ideas even when they are not highly certain about their creative potential. Members can also be confident that they will be joined by colleagues to brainstorm together once they ask. Finding a breakthrough in this manner in innovative organizations is reported as experienced multiple times during a single project (Brown, 2009; Dunbar, 1997; Kelley, 2001).

**Insights for Future Work**

We provide four suggestions for continued research and discussion: First, individual members, before they ask for a group idea generation meeting, would need to be given sufficient time and autonomy to generate ideas alone (Amabile et al., 2014; Brown, 2009; Kelley, 2001; Osborn, 1953), preferably until they hit a wall (Sutton & Hargadon, 1996). Since it has been reported to be the experience of being "stuck" (Amabile et al., 2014; Sutton & Hargadon, 1996, p. 703), when an individual is motivated to ask for an interactive session, it would be infeasible to propose an adequate amount of time for the individual session. Given the difficulty, researchers could survey extant laboratory findings that documented the moments by which an individual's momentum to generate ideas is substantially slowed down, e.g., five (Kohn & Smith, 2011) to twenty minutes (Christensen et al., 1957), depending on the nature and difficulty of the topic and their domain expertise. Relatedly, since it has been found that the medium (instead of too high or too low) level of time pressure is associated with increased creativity (Binnewies & Wörnlein, 2011), providing excessive, adequate, or scant time frame (or so perceived to create varying pressure) for individual idea generation before interactive idea generation might enable meaningful comparisons.

Second, the explicit request of an individual for an interactive session is probably a defining element in the complementarity between the social and individual factors in our systems model. If an individual has not yet exhaustively generated ideas, asking others for their time by convening an idea meeting would be unnecessary and may interfere with the productivity of even the one who requested the meeting. Also, if someone tries to offer an unsolicited advice for solving a creative problem, the individual who receives the idea might be less satisfied, feel imposed upon or face-threatened, and end up not utilizing the idea (see Chentsova-Dutton & Vaughn, 2012; Goldsmith, 2000; Van Swol et al., 2020). By contrast, ideas that are given to an individual, when that person had been experiencing an impasse and had asked for an interactive session, would be perceived as helpful—or breakthrough—ideas and would come with other emotional and social benefits. Thus, testing whether an individual has exhaustively generated ideas before asking for a group session affects productivity and emotion would be of most importance for validating the systems model of ideation.

Third, whether participants are in the nonlinear or linear frame-of-mind condition may affect the unconventionality of ideas that they generate, and this is likely to interact with which reasoning norm is in effect. This is because expecting that the innovative path is going to be nonlinear, with recurring phases of idea generation and evaluation, people would feel psychologically safer to err on the side of risk (see Baer & Frese, 2003) and to learn by doing (see Edmondson, 1999). This may be the case particularly in teams that consist of heterogeneous knowledge bases—or, ideally, relevant but varying expertise (Amabile et al., 2014)—than groups which are homogeneous (Stroebe & Diehl, 1994). For example, individuals with the nonlinear frame of mind and under the abductive norm may feel more comfortable to generate an idea even when they are uncertain about the idea quality. They would expect other members in the group with more relevant expertise will help evaluate the idea during a following evaluation phase. In contrast, groups in the linear frame of mind and/or with more homogeneous members may prefer generating safer alternatives.

Fourth, given the systems model is proposed primarily on the basis of face-to-face (FtF) ideation paradigm, using electronic ideation instead may alter the proposed dynamics in the model. Group electronic brainstorming, for instance, has been found in a meta-analysis to enhance idea quantity and quality in comparison to FtF real-group brainstorming and increase idea quantity even in comparison to FtF nominal-group brainstorming as long as the electronic brainstorming group is large enough (e.g., with 8 or more members, DeRosa et al., 2007). Nevertheless, it still seems unlikely that electronic idea generation would provide the various non-idea benefits, e.g., reinforcement of organizational norm, socializing, status auction, networking (Dennis & Reinicke, 2004), or immediate verbal and nonverbal evaluative feedback by others (Kerr & Murthy, 2004), at the levels possible with FtF communication, meaning there may be a trade-off between efficiency in idea generation and non-idea benefits in using either electronic or FtF communication. With the increasing reliance on communication technologies with new affordances (e.g., recently, video-conferencing), the number of possible combinations of the social and individual factors in the systems model of ideation will only increase and invite more research on this topic.

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# Appendices

## Appendix A: Survey items for hybrid (all-noninteractive) groups in Study I

*Vision*

1. Our group had one clear goal. (I had a clear goal during the task.)
2. Our group agreed on what was important to us. (I understood what was important during the task.)
3. Our group had a clearly shared understanding of the objectives and rules that guided our conversations. (I had a clear understanding of the objectives and rules that guided my performance.)

*Vigor*

1. During the task, my group was full of energy. (During the task, I was full of energy.)
2. My group was very resilient during the task. (I was very resilient during the task.)
3. When the task was finished, my group had quite some energy left for other activities. (When the task was finished, I had quite some energy left for other activities.)

*Absorption*

1. During the task, we forgot everything else around us. (During the task, I forgot everything else around me.)
2. My group was immersed in the task. (I was immersed in the task.)
3. Time was flying when my group was working. (Time was flying when I was working.)
4. It was difficult for the group to detach from the task. (It was difficult for me to detach from the task.)

*Task Attractiveness*

1. I liked the guidelines for brainstorming in this group. (I liked the guidelines for brainstorming.)
2. Our group gave me a good opportunity to experience creative thinking. (It was a good opportunity to experience creative thinking.)
3. We enjoyed following the brainstorming rules offered. (I enjoyed following the brainstorming rules offered.)
4. Members of our group were satisfied with the intensity of brainstorming during the task. (I was satisfied with the intensity of brainstorming during the task.)

## Appendix B: Survey items for Study III

*Norm Preference*

Please compare the three rules.

1. I really liked how “[past experience/characteristic/possibility]” was supposed to be used to generate creative ideas.
2. Following "[past experience/characteristic/possibility]" to generate creative seemed reasonable to me.
3. I was personally inclined to use "[past experience/characteristic/possibility]" to generate creative ideas.

*Perceived Performance*

Please compare the three rules.

Using [past experience/characteristic/possibility],

1. it was mostly up to me how I used this rule to be creative.
2. (Reverse-coded) there was very little I could do.
3. I was completely in control to generate creative ideas.
4. I had a lot of freedom of thought.
5. (Reverse-coded) was limiting my creativity.
6. I could generate a greater number of creative ideas.
7. I could generate more useful ideas.
8. I could generate more original ideas.
9. I could generate more creative ideas.

*Task Comfort*

Please compare the three rules.

Using [past experience/characteristic/possibility],

1. (Reverse-coded) I felt very tense to generate creative ideas.
2. (Reverse-coded) I was anxious to generate creative ideas.
3. I was more relaxed to generate creative ideas.