

Real-Life Neuroscience: An Ecological Approach to Brain and Behavior Research

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Abstract

Owing to advances in neuroimaging technology, the past couple of decades have witnessed a surge of research on brain mechanisms that underlie human cognition. Despite the immense development in cognitive neuroscience, the vast majority of neuroimaging experiments examine isolated agents carrying out artificial tasks in sensory and socially deprived environments. Thus, the understanding of the mechanisms of various domains in cognitive neuroscience, including social cognition and episodic memory, is sorely lacking. Here we focus on social and memory research as representatives of cognitive functions and propose that mainstream, lab-based experimental designs in these fields suffer from two fundamental limitations, pertaining to person-dependent and situation-dependent factors. The person-dependent factor addresses the issue of limiting the active role of the participants in lab-based paradigms that may interfere with their sense of agency and embodiment. The situation-dependent factor addresses the issue of the artificial decontextualized environment in most available paradigms. Building on recent findings showing that real-life as opposed to controlled experimental paradigms involve different mechanisms, we argue that adopting a real-life approach may radically change our understanding of brain and behavior. Therefore, we advocate in favor of a paradigm shift toward a nonreductionist approach, exploiting portable technology in semicontrolled environments, to explore behavior in real life.

Keywords

Social interactions, memory, episodic memory, methodology, behavioral, neuroscience, social cognition

Human behavior is largely determined by complex interactions with our environment. Despite this fact, conventional experimental psychological approaches have mainly focused on investigating behavior of individuals as isolated agents situated in artificial, sensory, and socially deprived environments, limiting our understanding of naturalistic cognitive, emotional, and social phenomena. Cognitive psychology and cognitive neuroscience thereafter have traditionally addressed the questions of how psychological functions are produced by neural circuits by condensing complex naturalistic processes into reductionist forms of computerized tasks or questionnaires. Furthermore, functional neuroimaging methodologies largely rely on data collected from participants tested in highly restricted environments, devoid of the contextual qualities and behavioral actions that comprise our daily experiences (Fig. 1a).

By real-life cognition or neuroscience, we refer to behavioral and neural processes that are set in environments relevant to daily life and involve familiar types

of stimuli and naturally occurring responses (Fig. 1h). It is increasingly acknowledged that the field of cognitive neuroscience may be hampered by the limited ecological validity that characterizes the bulk of paradigms and settings in the field, resulting in a shift toward the study of human behaviors in natural environments (Dudai, 2002; Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2002; Zaki & Ochsner, 2009).

In surveying the history of modern psychological science, a boost in the discipline is apparent during the early 20th century. Until the late 19th century, philosophers studied the mind and human behavior, largely on the basis of introspection and subjective experiences (D. P. Schultz & Schultz, 2015). Experimental psychology as a discipline detached from its philosophical

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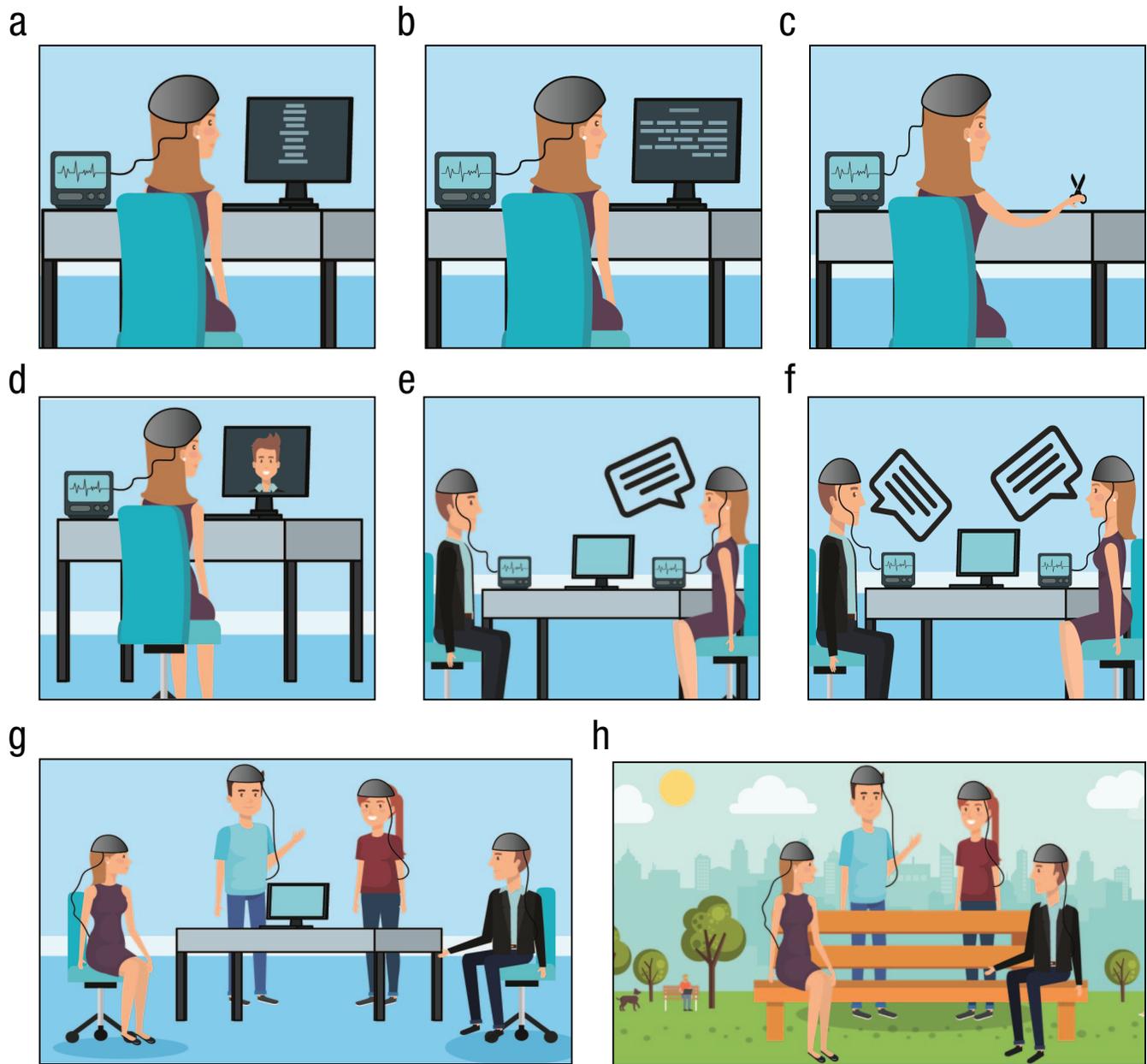


Fig. 1. Experimental approaches in cognitive neuroscience. (a) A traditional lab-based approach for testing human cognition, depicting a motionless participant presented with artificial stimuli such as a meaningless word list. The participant is limited in her responses and cannot affect the situation (person-dependent limitation), and the stimulus is isolated from a real-life context (situation-dependent limitation). (b) The participant is presented with meaningful stimuli (e.g., a story) but is unable to affect the situation (situation dependent). (c) The participant can explore an object, introducing higher level of activity, but the context is limited, and the participant is unable to move freely. (d) Depiction of the participant observing artificial social stimuli (the man protagonist) presented on a screen. (e and f) Lab-based unidirectional and dyadic bidirectional interactions. In a bidirectional design, the woman (in this example) may exchange information and receive feedback from the man, although the context is limited (situation-dependent limitation). (g) A multibrain interaction allows examination of group dynamics in the lab. (h) Finally, a real-life multidirectional interaction is shown in which the participants are part of a group and the situation is evaluated based on multiple interactions in natural surroundings. This final approach allows measuring of social interactions in real-life situations and assessing real-life memory.

roots only when methodological tools that were applied at the time in biology and physics were combined with controlled observations and experimentation. Wilhelm Wundt, who may be described as the founder of experimental psychology as an academic field, in attempting

to apply methodological techniques that were commonplace in natural science, took the first steps toward establishing the modern psychology lab (Dhimi et al., 2004). By pushing away from the philosophical roots of psychology, he started the tradition of systematic

experimentation of human behavior and cognition, practices that still resonate by and large with today's experimental settings (D. P. Schultz & Schultz, 2015). Cognitive science, initially established as a counter-movement to the absolute domination of behaviorism, started to form during the middle of the 20th century and matured to encompass a large fraction of experimental psychology, using experimental practices that emphasized highly reductionist, laboratory settings. The disappointment from the sterile laboratory settings that do not represent naturally occurring behavior was famously argued by Brunswik (1949), who introduced the term *ecological validity* to justify the opposition of representative design (i.e., the real-life approach) to systematic design (i.e., traditional approach).

One notable exception to the reductionist approach was, ironically, one of the founders of cognitive psychology, Ulrich Neisser, who expressed a grave disappointment in the observation that the field had succumbed to using experiments with extremely low ecological validity (Neisser, 1991). The problem of low ecological validity in cognitive psychology and later in cognitive neuroscience was perhaps exacerbated by the dramatic and complete dominance of the personal computer as a means to present experimental tasks. The growing use of neuroimaging techniques such as functional MRI (fMRI) during the 1990s further boosted the development of computerized paradigms that restrict behavior to passive viewing of simple stimuli or button presses because these techniques are highly sensitive to movement. Along with the obvious advantages in precision, controllability, and measurability, the abundant usage of computers for managing experiments fixated subjects as motionless participants in highly artificial tasks, with discrete, "clean" stimuli, situated in secluded environments, removing altogether most of the components found in natural, everyday behavior. Here we argue not only that such paradigms are removed from everyday experience but also that—similar to what Brunswik (1949) argued already more than a half century ago—the systematic designs commonly used in psychology disserve the very phenomena they investigate (Dhami et al., 2004).

Although the need to shift toward real-world experimental settings has been acknowledged for decades, this approach has gone through a period of rapid expansion with the advent of portable neuroimaging systems. Selective reviews of "real life" have been written in the past few years (e.g., Hasson & Honey, 2012; Schilbach et al., 2013), yet comprehensive reviews have yet to capture the breadth of the area. The importance of designing ecologically valid paradigms in psychology and neuroscience has been addressed by numerous commentators across fields, including developmental

psychology (Fabes, Martin, Hanish, & Updegraff, 2000), neuropsychology (Sbordone & Guilmette, 1999), and social psychology (Koehler, 1996). Nonetheless, although the real-life approach is relevant to all fields of psychology and cognitive neuroscience, the fields of social neuroscience and episodic memory—the primary focuses of the present review—are particularly relevant.

A prominent aspect of everyday real-life behavior and cognitive functioning involves the interplay between social cognition and episodic memory. These mental processes, typically studied in isolation, perhaps epitomize, better than any other, the crux of human experience. As highly developed social creatures, humans allocate a significant proportion of their cognitive processing toward interpersonal interactions set within social settings. As stated by Hirst and Manier (1999), "we cannot divorce the act of remembering from the act of communication." In fact, autobiographical memories are viewed by some as a key element of social encounters (Hirst & Echterhoff, 2012). Thus, not only is the content of autobiographical memory (AM) filled with past episodes of social encounters (Spreng, 2013), but also AM often emerges in the context of social interaction and may be crucial to the development of this cognitive function (Nelson & Fivush, 2004). Studying episodic memory and social interactions in sterile laboratory paradigms may overlook the crux of the cognitive processes that underlie these functions.

Indeed, because of the importance of understanding social behavior in natural settings, the fast-growing field of social neuroscience recently took a step toward understanding real-life interactions, demonstrating that brains react differently to passive viewing of social stimulations compared with active participation in social exchange with others (e.g., Schilbach et al., 2013). The review by Schilbach et al. (2013) presented compelling evidence showing the centrality of face-to-face interaction and emotional engagement in facilitating social understanding. The authors suggested that social behavior differs fundamentally in multiple aspects when it is examined from what they term a *spectator view* (when participants observe a social interaction) compared with engagement in a real interaction. Schilbach et al. focused on discussing how emotional engagement in understanding other minds is a basic part of social cognition, as opposed to merely reflecting on others' behaviors. They emphasize interactions among minds-brains and the importance of studying social engagements in the presence of social occurrences (second-person neuroscience).

Indeed, most paradigms in the field of social cognition are based on computerized tasks in which participants passively observe decontextualized social stimuli

such as still pictures of facial expressions or an isolated scene depicting a social interaction (e.g., Fig. 1d). In these types of tasks, participants are commonly required to make social judgments or emotional evaluations of decontextualized social scenarios using forced-choice rating scales. Given that social interactions by their nature require active participation in an interactive social exchange with social agents, measuring a response of an isolated passive observer may fail to capture the core mechanisms of social interactions.

Likewise, the study of human memory has tended to examine retention of discrete elements of information, devoid of context (G. Cohen, 2008). This practice is particularly striking in the field of episodic memory, defined as the uniquely human capacity to reinstate multisensory, content-rich information from the past, typically characterized by meaningful, often socially mediated occurrences and contextual detail (Tulving, 1985). Although many have advocated in favor of shifting toward an ecological approach of memory research (Neisser, 1991), it has largely been dominated by studying “microevents,” consisting of discrete elements, such as words lists or pictures that are presented to a captive audience of a single, passive participant (Cabeza & Nyberg, 2000). Although such studies meet the dry criterion of episodic memory—the when and where of the targeted events—the stimuli themselves lack the contextual, emotional, interactive, and narrative nature of everyday-life events, which are key features of the original definition of episodic memory (Piolino, Desgranges, & Eustache, 2009). Moreover, because the information to be learned is context-free and often meaningless, memory in such experiments is typically tested in time scales of minutes to hours after the stimuli were first presented, precluding the examination of long-term memory mechanisms. Taken together, what is conveniently referred to in the literature as *episodic memory* is often actually the examination of memory for miniepisodes, or miniature events that contain lists of items that have not yet been consolidated into long-term representations (Bruce, 1985). Here we argue that removing naturalistic components of everyday experience as they pertain to presented stimuli, contextual information, active participation, and bodily movement reduces ecological validity to the point that we are not advancing the understanding of behavioral and neural elements of the uses of memory in real life.

In the current review, we focus on social cognition and episodic memory as two separate (though related) representatives of cognitive functions and suggest that the traditional paradigms in these fields suffer from two key flaws that may potentially hinder advances in the field. The first flaw concerns person-dependent limitations. In

typical tasks, individuals are limited in their ability to act on the environment and participate or affect the events. The prevention of action and influence over the situation may interfere with the participants’ sense of agency. Furthermore, limiting participants’ movement may prevent the sensation of embodiment. The second restricting element concerns situation-dependent limitations. In most paradigms, cognitive abilities are measured in computerized tasks with limited contextual cues that only remotely resemble the richness of real-life experiences. Characterizing these person and context limitations could enable the development of real-life paradigms that allow participants to behave more naturally in ecological settings.

Whereas the review of Schilbach et al. (2013) focused mainly on the field of social neuroscience, the current review addresses two fields of study in psychology: social cognition and memory. In addressing the field of episodic memory, we hold that removing naturalistic components of everyday experience as they pertain to presented stimuli, contextual information, active participation, and bodily movement reduces ecological validity to the extent that we are not advancing the understanding of behavioral and neural elements of memory in real life. By discussing how the same limitations are relevant to the field of memory, this review makes a more general claim about ecological validity in cognitive neuroscience and demonstrates how this approach is relevant to different (if not all) fields of psychology.

In the following sections, we characterize these two limitations and how they pertain to the research fields of social cognition and memory, focusing on the need to consider the key features—embodiment, agency, and context. We then offer methodological suggestions for devising practical research avenues, using state-of-the-art technology, that may provide valuable insights into real-life behavioral and brain mechanisms of social cognition and memory. We argue here that conclusions drawn from controlled experimental designs with a limited number of variables may not be valid in real-life behavior. It is thus possible that incremental addition of complexity and context would not linearly correlate with complexity of the mechanisms tested. For example, the assumptions made in an experiment that tests emotion recognition in facial expression in a computerized task with an artificial, decontextualized, still picture (Fig. 2a) may not be applicable to emotion recognition in naturalistic settings (Fig. 2b). Thus, the point to be made here is that by clinging to highly reductionist experimental settings that are removed from our natural experiences, we might be inadvertently investigating cognitive functions that are at the fringe of human experience.

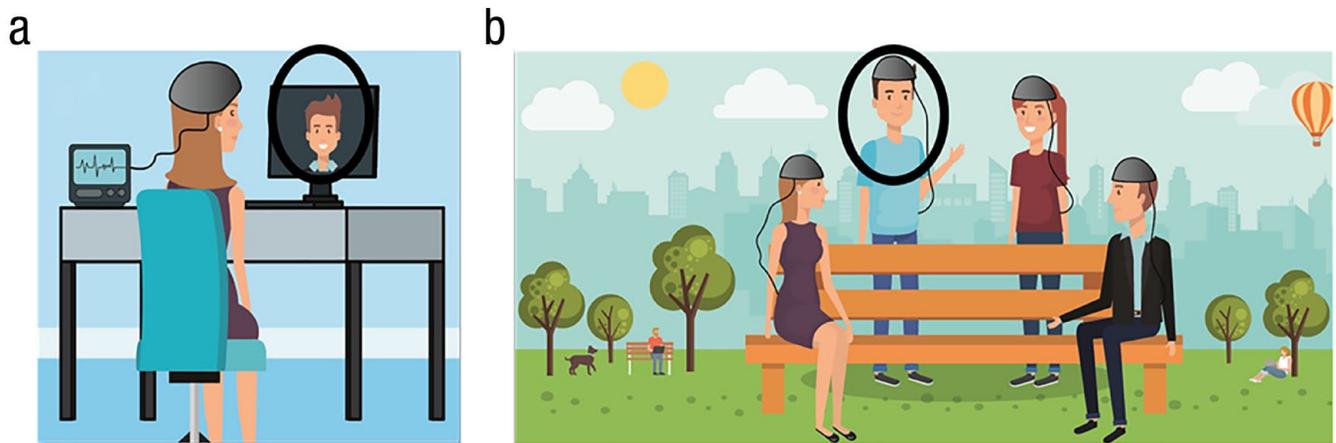


Fig. 2. Illustration of nonlinearity in controlled versus real-life designs. (a) The participant views a decontextualized facial expression. (b) The participant views the same face as part of a rich context that includes information regarding posture, environment, other people, and so on. The shift from emotion recognition in the lab to real-life behavior does not represent merely a linear increase in processing demands, because the underlying functions may be fundamentally different.

Person-Dependent Limitations: Not Being an Active Agent

A considerable amount of knowledge in psychology is based on subjective reports of participants. Traditionally, human behavior has been assessed with pencil-and-paper methods of administration and interviews. Modern psychology has gradually moved toward testing behavior using computerized tasks. The development of computerized methods for collecting data on a range of cognitive domains may also be related to the development of neuroimaging techniques that allow measuring behavior mainly in computerized tasks. Such computerized tasks allow highly controlled and precise presentation of stimuli across test sessions and participants. Critically, data may be analyzed with automatic scoring methods. A notable downside to such computerized tasks, however, is that they limit the natural behavior of the participant and restrict responses to button presses, which may interfere with basic cognitive processes. Critically, although there are fundamental differences between passive exposure and active exploration (e.g., Chrastil & Warren, 2012), many experimental paradigms in psychology involve passive viewing of stimuli. Here we argue that based on frameworks of agency and embodiment, limiting the participants' active response may fundamentally impede the understanding of basic cognitive functions.

Agency and cognition

Interfering with the ability of participants to act on the environment may reduce their sense of control over the environment, in turn affecting their sense of agency—the experience of controlling one's own actions (Chambon

& Haggard, 2012). It is common practice in neuroscience of social cognition and memory for participants to be passively presented with stimuli to which they are requested to judge or rate certain features. Although they sometimes receive indications as to the success of their judgment, participants do not typically affect the stimuli or the situation. That the actions of participants do not have an effect on the experience may diminish the engagement of participants in the tasks, reduce their sense of agency, and leave basic cognitive faculties dormant. Higgins (2014) argued that individuals strive to be effective in obtaining desired results and gaining control over the environment. Indeed, research on the tendency to possess a sense of agency indicates that it is a critical motivator of behavior. Accordingly, it has been shown that manipulating one's objective control over the environment influences both the speed and the frequency of performing an action associated with that control (Karsh & Eitam, 2015), indicating that the mere sense of control modifies behavior. How does the sense of agency interact with social cognition and memory functions?

According to Schillbach et al. (2013), merely observing a social agent devoid of actively engaging in social interaction may affect the level of emotional engagement in a social task. The authors argued that traditional studies in psychology are based on a spectatorial view, in which a detached observer reads out the mental states of another person, who in turn is not affected and cannot react to other people. Critically, the authors claimed that social cognition is fundamentally different when individuals are emotionally engaged in a social situation compared with being a spectator of a social scenario. Thus, what is conveniently referred to as social cognition in numerous studies might be qualitatively different from what the conceptual terms imply.

In line with this framework, it was suggested that the fundamental differences between social observation and social interaction may predict the involvement of distinct brain regions in these two situations. Corroborating this notion, Tylén, Allen, Hunter, and Roepstorff (2012) reported a distinction between social observation and social interaction by demonstrating that perceiving an interactive gesture (e.g., someone offering or presenting an object) elicits activations in regions corresponding to a model of coupled dynamics (joint action). In contrast, perceiving someone “privately” manipulating an object elicited activation in regions typically associated with theory of mind and the mirror neuron system.

Although the study by Tylén et al. (2012) does not involve a real-life social exchange, it is unique in that it exhibits dissociable activations during participatory versus observational conditions, supporting the notion that passive social cognition and interactive social engagement are dissociable functions.

Indeed, numerous paradigms in the field of social neuroscience involve passive viewing of static images, cartoons, video animations, or story reading (Molenberghs et al., 2016). Conversely, paradigms of interactive games, such as strategic decision making, allow participants to actively engage in live interactions, thus strengthening subjects’ sense of agency. Employing strategic games requires that participants engage in actively making decisions in light of incoming information associated with differential gains. Designing such experiments requires careful consideration of the processes relevant to behaviors of interest and tasks that allow for modeling actions relevant to real-life behavior (Montague et al., 2012). Indeed, the increasing use of paradigms adapted from behavioral economics can benefit the ecological validity if suitably applied to studying social cognition. For example, Hampton, Bossaerts, and O’Doherty (2008) created a strategic game that assesses competitive interactions between “employer” and “employee” and scanned participants with fMRI during an online two-player strategy game. Whereas previous studies that used passive viewing of vignettes demonstrated equal activity in various components of the mentalizing network—for example, the medial prefrontal cortex (mPFC) and superior temporal sulcus (STS)—during mental-state attribution (e.g., Jenkins & Mitchell, 2009), Hampton et al. found that mentalizing-network components made dissociable contributions to the computations underlying competition.

Note that in Hampton et al. (2008), the activity of the mPFC was predicted by activity of the ventral striatum, indicating that mentalizing during interaction involves activity in the reward circuitry. Pursuing the idea that the reward mechanisms participate in “live”

social interactions, Phan et al. (2010) used a “trust game” task involving iterative exchanges and showed that reciprocity engages the ventral striatum. Likewise, real-time cooperation was shown to activate both the mentalizing network and the reward circuitry (Krill & Platek, 2012). Whereas Schilbach et al. (2013) addressed the issue of agency and how it affects engagement, the above findings demonstrate that providing the opportunity to actively engage with one’s environment entails a shift in the underlying supporting brain networks and not merely a linear change in the networks involved in passive tasks of similar nature. One prominent brain structure that recurs in studies that involve strategic games is the ventral striatum, indicating the engagement of reward-related learning when social interactions are involved. Nonetheless, although strategic games such as the ultimatum and trust games bring us closer to understanding the behavioral and neural mechanisms of cognition by enhancing the sense of agency, they only remotely resemble real-life, face-to-face interactions in which the range of responses and the ability to act on the environment are far richer.

Being an active agent in an ongoing event is not only significant for social interaction but can also affect memory formation and future recollection of experiences (Butler & James, 2013; Carassa, Geminiani, Morganti, & Varotto, 2002; Plancher, Barra, Orriols, & Piolino, 2013). Memories of experiences are formed whether the individual is a passive part of the occurrence or an active agent (actively interacting with the environment). The question at hand is whether the degree of perceived control over the environment may affect memory properties associated with relevant experiences. There are now several lines of evidence supporting the notion that actively interacting with the environment can affect memory formation (Brandstatt & Voss, 2014; Carassa et al., 2002; Murty, DuBrow, & Davachi, 2015; Plancher et al., 2013; Rotem-Turchinski, Ramaty, & Mendelsohn, 2019). For instance, spatial memory in a virtual environment was found to be stronger when individuals performed active rather than passive exploration of the environment (Carassa et al., 2002). Likewise, memory for words that were generated by participants was somewhat superior to memory for words that were passively assigned to subjects (Vinogradov et al., 2006). This latter study detected a different pattern of brain activity in the dorsomedial PFC and anterior cingulate cortex during correct retrieval of self-generated words compared with retrieval of passive words.

A recent study examined whether the act of a simple choice opportunity affects declarative memory performance (Murty et al., 2015), emphasizing the involvement of the mesolimbic-dopaminergic system in enhancing

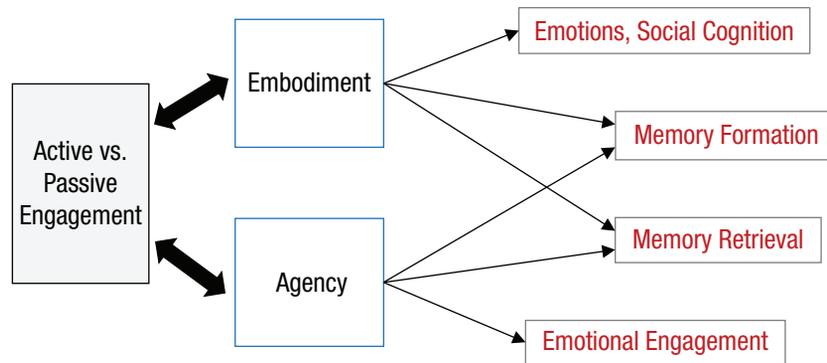


Fig. 3. A schematic description of the influence of participants' active versus passive role in cognitive processes. Via the notion of embodiment, restricting activity may affect different stages of memory as well as the way emotions and social interactions are perceived. The level of activity can also engender a sense of agency, in turn again affecting memory functions as well as emotional engagement in social encounters.

declarative memory encoding in humans (Murty & Adcock, 2014). This study is an example of memory amplification in the absence of external reinforcement—in this case, the opportunity to choose even in the absence of a correct answer. The working hypothesis was that by providing the opportunity to choose, individuals generated a feeling of control and ability to affect the environment, which served in turn to enhance memory performance (Rotem-Turchinski et al., 2019). From the aspect of brain activity, the improvement in memory performance was linked to interactions between striatum activation immediately before choice phases and hippocampal activity thereafter during successful memory encoding of presented items.

A rising notion in the field of interactive memory systems is that dopaminergic inputs to the hippocampus mediate a functional link between the reward-related mesolimbic system and declarative memory formation (Shohamy & Adcock, 2010; Wittmann, Dolan, & Düzel, 2011; Wittmann et al., 2005). In light of the results of Murty and Adcock (2014), and particularly their finding that the striatum is involved in the active-induced memory effect, it can be argued that the act of choosing can serve as a reward. Gruber, Gelman, and Ranganath (2014) found that heightened states of curiosity benefit hippocampus-dependent learning via the dopaminergic circuit. These studies support the notion that the opportunity to actively participate in an ongoing event and affect its consequences is perceived as a positive occurrence in itself, generating a motivational signal that may affect diverse memory systems (Shohamy & Adcock, 2010).

To summarize, a sense of agency entails a feeling that one's actions influence the environment. The above literature survey indicates differential neurobiological underpinnings of passive versus active processing both

in the social and memory domains (Fig. 3). Social interactions are interpreted differently, and formation of memory as well as retrieval are boosted once individuals engage in the encoding event. Specifically, it appears that the striatal inputs to the mentalizing network during social interaction and to the hippocampus during active memory formation play a key role in mediating these effects. These links may provide a potential mechanism that mediates the effect agency on cognition.

Having an active or passive role in a situation is significant not only in participants' sense of agency but also in their embodied cognition. In the following section, we highlight the effects that restricting the movement of participants may exert on embodied cognition.

Embodied cognition

Many paradigms that involve passive viewing of stimuli (instead of active participation in an event) also require that the participant limit his or her body movement. According to the embodied cognition theory, various cognitive abilities, including high-order ones (e.g., conceptualization, memory retrieval, empathy), are reliant on and affected by environmental features surrounding the agent, taking into account such dimensions as sensory input processing, bodily interactions with the environment, and action execution. The embodied cognition framework thus views cognitive processes as dependent on bodily sensations and somatosensory and motor resources (Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). According to this theory, bodily experiences play an integral role in representations such that not only bodily sensations but also bodily postures, gestures, and expressions are inherent components of cognition and can exert covert yet potentially significant impacts on perception, memory,

language, social cognition, and emotions (Barsalou, 1999). Schilbach et al. (2013) discussed the issue of embodiment as affecting engagement in social interaction. Here we take a step forward and argue that not moving may affect basic emotional and cognitive process. Indeed, it is increasingly acknowledged that body movements (e.g., Meier, Hauser, Robinson, Friesen, & Schjeldahl, 2007), gestures (Chandler & Schwarz, 2009), and facial-muscle contractions (Parzuchowski & Szymkow-Sudziarska, 2008) influence emotions and social cognition (see Barsalou, 2008; Niedenthal et al., 2005). The close relationship between bodily motion and emotion is evident in the fact that both words derive from the same Latin root word, *movere* (“to move”). Indeed, in social and emotional situations, people act, react, and move their hands, torso, legs, and faces.

It stands to reason that the tendency to use physical bodily movements during emotional experiences and social behavior is acquired from early stages of development, when associations are made between emotions and bodily experiences. In adulthood, the link between movement and mental representation becomes bidirectional. Emotions trigger movements, and movements may trigger emotions. For example, if during early social interactions we learn that interpersonal touch such as hugging or hand-holding involve physical warmth, we may associate physical warmth with affection. As a result, merely holding a hot cup of coffee may increase the evaluations of a protagonist's levels of psychological warmth (Williams & Bargh, 2008) or friendliness (IJzerman & Semin, 2009), and higher oral temperature readings may be associated with greater feelings of social connection (Inagaki, Irwin, Moieni, Jevtic, & Eisenberger, 2016).

Likewise, it has been shown repeatedly that bodily actions and postures can influence emotional experiences. Changing one's body posture can affect performance on various tasks as well as the accompanying feeling. For example, when asked to self-evaluate performance outcome, participants express more pride after sitting in an upright position than after slouching down (Stepper & Strack, 1993). Furthermore, it has been shown that, compared with reclining, leaning forward (associated with a heightened urge to approach stimuli) causes participants to generate heightened late positive potential responses to appetitive but not neutral pictures, suggesting that body postures may modify electrocortical responses (Price, Dieckman, & Harmon-Jones, 2012). These studies indicate that emotions can be reliably triggered or enhanced when corresponding behaviors are produced. Critically, these reports imply that when movement is limited, one's ability to represent the associated emotion corresponding to the relevant changes in bodily movement is diminished.

Limiting the ability to actively move during social interactions may therefore interfere with the way we perceive and recognize emotional and social stimuli.

Bodily postures and signals seem to play an important role in memory formation as well, particularly when manipulated during encoding. A set of studies that examined memory performance following either active or passive participation during encoding by employing a paradigm termed *subjects-performed task* concurred with this notion. In these experiments, participants are required to either actively perform the behavior associated with a particular instruction (e.g., laugh, sharpen the pencil) or passively listen to the task instruction without performing it. Immediate and long-term recall tests are followed, in which participants are instructed to write as many tasks as they can remember (R. L. Cohen, 1981). Indeed, actions that were actively carried out yielded higher levels of recall than their passive counterparts (Engelkamp & Zimmer, 1989), yielding a so-called enactment effect (Hainselin, Picard, Manolli, Vanerkore-Candas, & Bourdin, 2017). Furthermore, it was demonstrated that merely imagining action performance similarly leads to heightened recollection levels (Dick, Kean, & Sands, 1989; Engelkamp & Zimmer, 1989; Steffens, von Stülpnagel, & Schult, 2015). In a similar vein, using an object while performing a task can promote memory performance for those objects (Brooks, 1999; Engelkamp & Zimmer, 1997). It seems that the involvement of motor sequences during encoding benefits memory by forming multimodal associations (Engelkamp & Cohen, 1991). Further support for the boosting effect that action has on memory formation comes from studies that afford participants the possibility to actively navigate in a virtual environment. Here, active participants recall the spatial organization of a virtual reality setting better than passive participants. This finding suggests again that the motor system (moving a joystick) influenced the encoding of a spatial layout (Brooks, 1999).

Because memory performance can benefit from providing conditions that resemble those that were available during encoding (Thomson & Tulving, 1970), it follows that adjusting bodily positions to resemble the encoding state should facilitate retrieval (Dijkstra, Kaschak, & Zwaan, 2007; Dijkstra & Zwaan, 2014). Indeed, participants' autobiographical memory performance tends to profit from retrieval in positions similar to those in which the encoding took place (Dijkstra et al., 2007). Such findings were taken to indicate that bodily positions entail a sensorimotor component of the original experience, facilitating its reconstruction during retrieval. Bodily positions can also serve as cues to memories that seem appropriate to certain postures. For example, individuals tend to recall negative life

events when sitting in a slumped position, whereas an upright position favors recollection of positive occurrences (Riskind, 1989). Therefore, to fully understand the mechanisms that enable episodic memory, it is useful to account not only for audiovisual information presented to a passive agent but also for aspects relating to kinesthetic and affective properties of the encoded experience (Wilson, 2002).

Although several studies on embodiment reported here were carried out in highly controlled environments, the evidence described above provides a compelling showcase that restricting one's body movement may have direct influences on cognitive performance. The effects of embodied cognition are apparent in emotional experiences and social behaviors as well as memory encoding and retrieval.

Situation-Dependent Limitations: Being Out of Context

Ample research implies that not only our bodies but also the physical environment and the social context of cognition can influence cognitive processing (see Barsalou, 2010). In natural environments, we perceive information in a vivid and dynamic context. Social situations in particular are characterized by their dynamic input, involving simultaneous processing of faces, bodies, vocalizations, and odors. Likewise, memories are encoded in complex and often unexpected combinations of a multitude of physical features. Nevertheless, the reductionist approach to scientific methodology and psychology research within it has dictated the division of cognitive functions into tasks tested separately under highly controlled conditions. By focusing on discrete components and avoiding confounding variables, psychologists have developed paradigms that use simple stimuli devoid of their natural context. Whether understanding complex stimuli can necessarily be predicted from responses to decontextualized settings is an open question.

One of the defining features of real-life situations is context. Items are not perceived in isolation because they are typically associated with background features, together creating a continuous stream of spatial and temporal information to extract the bigger picture from the details. Studying contextual features of social situations such as group membership and group dynamics is essential for understanding social processes. Likewise, context is central to the understanding of real-life memory processes. For example, studies suggest that having prior (semantic) knowledge regarding tested stimuli enhances future retention, supporting the notion that encoding information in natural settings strengthens consolidation by assigning meaning to the

information, something that is not typically achieved in laboratory settings (Steyvers & Hemmer, 2012). Thus, very different conclusions can be drawn from memory studies that use naturalistic stimuli versus discrete items as memoranda.

Controlled stimuli have been essential to elucidating the neural basis of distinct cognitive functions, including complex ones such as social cognition properties and memory formation. For example, in experiments that examine face processing, faces are typically presented in isolation, separated from the body, and in many cases with no hairline or color (i.e., in black and white). A major strength of using simple stimuli is that they are ideal for determining their relationship with a specific response of specific brain networks (e.g., the fusiform face area, or FFA, and face processing). Nonetheless, such stimuli are deprived of their natural setting and are not representative of their appearance in their natural setting. Our daily experience in real-life settings teaches us that interactions with human faces are rarely presented as constant, stationary input. In fact, facial motion and dynamics are critical for perceiving the identity of a person (Pilz, Thornton, & Bülhoff, 2006) and his or her emotional state (Calvo, Avero, Fernández-Martín, & Recio, 2016). It has been suggested that changeable dimensions of faces (e.g., emotional expressions, eye gaze) are mediated by the STS (Blakemore & Decety, 2001; Grossman, Blake, & Kim, 2004), whereas static dimensions (e.g., face form) are processed by the FFA (Grill-Spector, Knouf, & Kanwisher, 2004; Haxby, Hoffman, & Gobbini, 2000; Kanwisher, McDermott, & Chun, 1997; Kanwisher & Yovel, 2006). Emerging data suggest that dynamic faces activate the face-processing network more consistently than static faces (Fox, Iaria, & Barton, 2009; J. Schultz, Brockhaus, Bülhoff, & Pilz, 2013), implying a stronger interaction between the neural pathways involved in processing changeable and invariant facial information than previously assumed. It is possible that the more natural form of moving social stimuli draws more attentional resources than their static counterparts (Franconeri & Simons, 2003) and therefore evoke increased neural resources (Corbetta & Shulman, 2002).

In addition to moving and dynamically changing stimuli, seldom are simple stimuli detached from their context in real life. We perceive faces while considering the body posture, the odors, the clothing, the social situation, and the person identity (De Gelder, 2016). Indeed, recent evidence indicates that the context plays an important role in determining how emotional facial expressions are recognized. For example, in contrast to the prevailing view that facial expressions are prominent indicators of emotional states, the perception of basic facial expressions has been found to be highly

dependent on body cues and can be categorically altered by context at early perceptual levels (Aviezer et al., 2008). In line with this, a recent event-related potential (ERP) study has showed that body expressions affect the neural processing of facial expressions in children as young as 8 months old (Rajhans, Jessen, Missana, & Grossmann, 2016).

To increase the vividness of stimuli, researchers in social neuroscience have attempted to use cinema clips, which are multimodal in nature, engaging snapshots of reality, and often describing human interactions in realistic conditions. Using clips from movies permits higher ecological validity than short presentation of still pictures (Haxby et al., 2011) and also enables analysis of intersubject correlation analysis (ISC; Hasson, Nir, Levy, Fuhrmann, & Malach, 2004). The ISC approach allows the measurement of neural responses to extended naturalistic stimuli (e.g., movies); the responses in one brain are used to predict responses in another brain perceiving the same stimulus. Although this method allows examining coupling between brain activity of multiple participants, it does not measure real-time coupling during real-life, face-to-face interactions. Critically, as much as the stimuli presented in movies are more embedded in a natural context, having a participant passively view a scene from a movie is less engaging than real social interaction that involves feedback.

Films of varying lengths have been used as learning material in memory research as well, attempting to balance between controlled stimuli while maintaining its rich and contextual nature (Ben-Yakov & Dudai, 2011; Furman, Dorfman, Hasson, Davachi, & Dudai, 2007; Furman, Mendelsohn, & Dudai, 2012; Mendelsohn, Chalamish, Solomonovich, & Dudai, 2008; Mendelsohn, Furman, & Dudai, 2010; Mendelsohn, Furman, Navon, & Dudai, 2009). Whereas lists of words or pictures leave only a short-lived trace, the content and details of movies can persist in memory for long and even remote periods (Furman et al., 2007; Furman et al., 2012). The brain network that corresponds with retrieval of movie details appears to highly overlap the autobiographical memory network (Mendelsohn et al., 2010), which can be easily distinguished from networks associated with lab-based memory retrieval (Burianova & Grady, 2007; Cabeza et al., 2004; McDermott, Szpunar, & Christ, 2009). Although such paradigms bring us closer to unveiling the behavioral and neural underpinnings of the different stages of long-term episodic memory, they still lack a crucial aspect of memory for real-life events: the firsthand, egocentric experience of actual involvement in an ongoing event. Studying real-life autobiographical memory poses several challenges: First, the experimenter typically lacks access to and control over the encoded occurrences; second, because each

individual retrieves particular events from his or her past, it is difficult to aggregate information across subjects; and finally, the accuracy of recollected memories cannot be assessed (Cabeza & St Jacques, 2007; McDermott et al., 2009). These challenges can be overcome by importing real-life settings into the laboratory, specifically by staging experimental setups that enable experience documentation (and therefore accuracy determination) and reproducibility across subjects.

Although rare, the real-life memory field has been encouraged by research groups that devised ways to probe retrieval of ecological yet documented events, labeling them with terms such as *autobiographical memory* (Cabeza et al., 2004; Henkel, 2014; St. Jacques, Rubin, LaBar, & Cabeza, 2008), *real-world episodic memory* (Davidson, Cooper, & Taler, 2016; Griffiths, Mazaheri, Debener, & Hanslmayr, 2016), *everyday recognition memory* (Milton, Muhlert, Butler, Benattayallah, & Zeman, 2011), and *personal memories* (St. Jacques & Schacter, 2013). A growing trend in the field employs the photograph paradigm (Cabeza et al., 2004). In these studies, participants wear a camera that automatically takes pictures from their daily experiences. These photos are used as retrieval cues in recognition tests after participants encode material from daily events (Milton et al., 2011), campus outings (Cabeza et al., 2004; St. Jacques et al., 2008), and museum tours (St. Jacques, Olm, & Schacter, 2013). Incidental memory brings us even closer to ecological validity such that by surprise tests of memory for documented events, researchers can examine accuracy and subjective strength of memories for occurrences that were not suspected to be tested thereafter (Davidson et al., 2016). It is noteworthy that these experimental setups provide the opportunity to illuminate neural mechanisms involved in both short- and long-term retrieval of such real-life documented events.

Experiments with interactive avatars are perhaps better at creating a seminatural vivid interactive environment. Artificial computer-generated environments offer the opportunity for participants to act and interact as if in a real environment. A major advantage of virtual environments lies in the presentation of realistic stimuli. Instead of passively watching a simple movie stimulus, subjects can interact actively within the environment. For example, it is possible to examine memory by creating an artificial environment in which the participant can navigate and explore an arena (Mueller, Fagan, & Grimm, 2011). Although virtual reality (VR) allows measuring behavior with an interactive environment, the behavior of the participants is limited, and the sense of reality is typically weak. The sense of presence in an environment depends on input from some or all sensory channels that are limited in the VR environment.

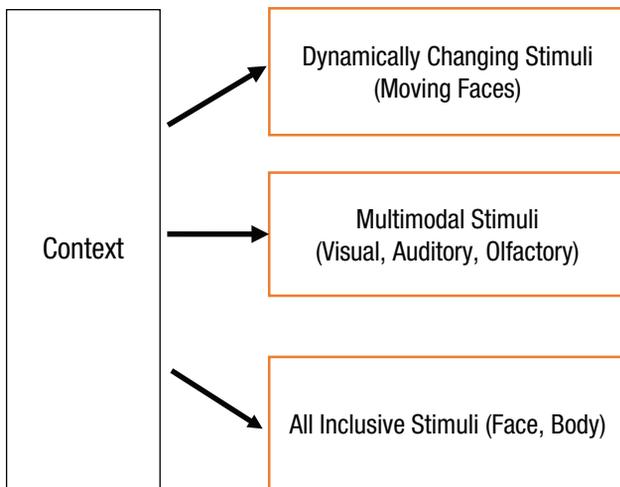


Fig. 4. A schematic description of the different dimensions of context. Cognitive neuroscience has made important steps toward the implementation of context in experimental designs by using film scenes, short stories, virtual environments, and real-life events. However, experimental paradigms in psychology should seek not only to incorporate a more elaborated context in experimental settings but also to integrate contextual properties into their theoretical models. For example, recent studies in social neuroscience use experimental designs that enable measuring brain signals from two participants simultaneously during real, face-to-face interactions (hyperscanning; see next section). In these studies, providing naturalistic context not only increases the ecological validity of experimental settings but also enables the investigation of new mechanistic questions regarding interbrain coupling and its contribution to social behavior. Combined with state-of-the-art technology designed to record and manipulate behavioral and neural responses (discussed in the next section), it is now becoming possible to conceive experimental designs that allow asking new questions about the effect of context on behavior, a feature that is discussed below.

A vivid visual display system might afford some individuals a sense of “reality” but be unsuited for others in the absence of sound (Slater, Usoh, & Steed, 1995). Indeed, recent VR studies with avatars show that beliefs about human agency of the avatar influence performance in the task. For example, it has been shown that specific brain responses (e.g., centroparietal P350 ERP) are sensitive to whether participants realize that they interact with an avatar based on a computer algorithm (Caruana, de Lissa, & McArthur, 2017). Collectively, it appears that different social contexts may differentially affect social processing such that the artificial context activates social networks to a lesser extent to the point in which certain networks will not activate when the context is limited (Fig. 4).

Measuring Brain and Behavior in Real Life

Given the limited ecological validity that characterizes the bulk of paradigms in neuroscience, there is a current

shift toward the study of human behaviors in natural environments (Dudai, 2002; Zaki & Ochsner, 2009). The use of real-life complex, dynamic, naturalistic stimuli provides a solid basis for understanding brain and behavior. First, compared with basic computerized tasks, real-life situations provide a natural context and allow dynamic movement and feedback. Second, collecting rich data from real-life experiments offers the opportunity to evaluate multiple variables across experiments possessing high ecological validity (Fig. 1h). Finally, the sampling of real-life behaviors entails high-level aspects of social behavior and memory that seldom come into play in lab-based experiments. In recent years, studies in the field of social neuroscience and memory attempted to design paradigms that involve real interactions and real-world experiences. Whereas traditional neuroimaging techniques including fMRI, magnetoencephalography, and electroencephalography (EEG) are limited in their ability to examine freely moving individuals in natural context, attempts have been made to create paradigms that allow investigating real social interactions (e.g., Dikker, Silbert, Hasson, & Zevin, 2014) and real-life memory (e.g., Cabeza & St Jacques, 2007; St. Jacques et al., 2013) using these methods. The implementation of real-life experiments in neuroscience could be executed with traditional neuroimaging techniques such as fMRI with paradigms designed to account for internal parameters such as sense of agency as well as external parameters such as context.

For example, Stephens, Silbert, and Hasson (2010) applied fMRI to record brain activity from both speakers and listeners during natural verbal communication and showed that the observed alignment of production- and comprehension-based processes is a potential mechanism of communication. Designing experiments that allow active participation in a vivid environment necessitates systems that can reliably measure brain activity in natural environments while being sufficiently portable. Newly developing portable neuroimaging techniques—for example portable EEG and functional near-infrared spectroscopy (fNIRS) systems—allow the measurement brain activity of freely behaving individuals in natural settings. EEG is the most frequently used portable technique (Scholkmann, Holper, Wolf, & Wolf, 2013), and one of its main advantages is its high temporal resolution. However, it still suffers from the limited ability to localize the epicenter of brain activation (Huettel et al., 2004). New fNIRS systems, which are highly portable, enable measurement of changes in cerebral blood flow (i.e., in oxyhemoglobin) during free movement. Despite obvious shortcomings of fNIRS (e.g., sensitivity to blood flow changes under the scalp that are unrelated to brain activation, low spatial resolution;

Gregg, White, Zeff, Berger, & Culver, 2010; Kirilina et al., 2012), it provides a promising way of localizing changes in cerebral concentration of oxygenated and deoxygenated hemoglobin in real-life situations.

To address the issue of decontextualized social environments, researchers are increasingly shifting toward examining individuals during face-to-face social interactions. Although traditional neuroimaging approaches are limited to measuring individuals responding to social stimuli presented on a screen (Fig. 1d), novel hyperscanning methods afford collecting data from individuals interacting with real social protagonists (Fig. 1f). The term *hyperscanning*, originally coined by Montague et al. (2002), describes the measurement of brain activity from two or more humans simultaneously, allowing the assessment of the bidirectional information flow between interacting individuals (Hari, Himberg, Nummenmaa, Hämäläinen, & Parkkonen, 2013; Konvalinka & Roepstorff, 2012). Hyperscanning in dyads (Fig. 1f) enables the measurement of interactive social interactions that include bidirectional flow of information between the protagonists, whereas hyperscanning in groups examines multiple interactions (Fig. 1g).

Hyperscanning enables creating a closed feedback loop across interacting individuals, and therefore it lends itself easily to social neuroscience studies (for a review, see Babiloni & Astolfi, 2014) but is similarly applicable to various other cognitive domains, such as memory encoding and retrieval processes. Measurements of coupling can include behavioral matching (coupled behavioral responses) as well as brain-to-brain coupling (Hasson & Frith, 2016).

Most studies with hyperscanning have been performed with EEG. These studies mainly focus on measurements of brain-to-brain coupling in the alpha-mu band (8–12 Hz) during tasks that involve imitation (Dumas, Nadel, Soussignan, Martinerie, & Garnero, 2010) or cooperation (Astolfi et al., 2010). In a pioneering study, Sänger, Müller, and Lindenberger (2012) examined brain-to-brain coupling during a guitar duet performance. The authors reported brain-to-brain coupling in the delta (1–4 Hz) and theta (4–8 Hz) ranges measured by frontal and central electrodes during periods that require musical coordination. Note that the inter- and intrabrain network associated with playing guitar in a duet differed significantly from that involved in passive listening to a partner play the guitar (Müller, Sänger, & Lindenberger, 2013), further demonstrating that being actively engaged in an interaction involves a different mechanism than passively viewing them. In a recent study, Goldstein, Weissman-Fogel, Dumas, and Shamay-Tsoory (2018) linked brain-to-brain coupling to the analgesic effect of social touch by showing that interbrain synchrony in the alpha-mu band predicts the

level of analgesia during handholding. These studies show that measures of brain-to-brain coupling along the EEG scale during live interactions allow understanding psychological questions in a way that was not possible before.

Studies on hyperscanning of dyads with fNIRS provide further important evidence for brain-to-brain coupling in cerebral blood flow of pairs of participants during social interactions. For example, studies using hyperscanning with fNIRS systems demonstrate increases in brain-to-brain coupling in prefrontal regions during various social behaviors, including cooperation (Baker et al., 2016; Cheng, Li, & Hu, 2015; Cui, Bryant, & Reiss, 2012; Funane et al., 2011; Liu et al., 2016), imitation (Holper, Scholkmann, & Wolf, 2012), face-to-face dialogue (Jiang et al., 2012), and coordinated singing (Osaka et al., 2015).

Although these initial efforts allow measuring the behavior of dyads, there is little research on behavior of humans in groups. Given that group living is a ubiquitous biological phenomenon throughout the animal kingdom (e.g., Alexander, 1974), studying the mechanisms underlying group processes and intergroup relations is critical for understanding human behavior. As illustrated in Figure 1g, interaction in a context of a group involves multibidirectional links between individuals. Only a handful of studies have focused on group behavior. Dikker et al. (2017) recently used portable EEG to record the brains of 12 students simultaneously during regular classroom activities. Group-based neural coherence analysis demonstrated that the extent to which brain activity is synchronized across students predicts both student class engagement and social dynamics, suggesting that brain-to-brain synchrony is a possible neural marker for dynamic social interactions. Likewise, Jiang et al. (2015) used fNIRS in groups of three participants in a paradigm that examined leadership in groups. The authors reported that brain-to-brain coupling for the leader-follower pairs was higher than that for the follower-follower pairs in the left temporoparietal junction, an area important for mentalizing. Critically, leadership could be successfully predicted on the basis of interbrain coupling. Finally, Nozawa, Sasaki, Sakaki, Yokoyama, and Kawashima (2016) recently used fNIRS to study groups of four subjects and showed frontopolar coupling during cooperative verbal communication. Given that single-brain-level analysis and paired-brain-level analysis may not fully capture the complexity of group behavior, these studies demonstrated that it is becoming possible to measure brain signals from multiple participants to examine group dynamics.

The main advantage of the hyperscanning approach is that it allows investigation of interbrain synchrony

between two or more brains. In addition, the experimental setting of these types of experiments enables real face-to-face interactions. However, it is not clear what interbrain synchrony represents. Showing interbrain synchrony during social interaction adds new measurements to the traditional intrabrain activation measures, but it remains unclear what this synchrony represents. A key question is how these coupling effects correlate with specific behaviors and how the activity of one brain affects the behavior of a partner. Finally, it appears that the use of hyperscanning is still limited to studies in social neuroscience. Given the tight link between episodic memory and social communication, it would be interesting to examine how brain-to-brain coupling underlies the formation of episodic memory for information relevant to social interaction. A recent study that addressed this issue with fNIRS found that interbrain synchrony between a learner and an instructor in the inferior frontal gyrus (IFG) predicts song learning, indicating that interbrain synchrony may be a mechanism of social learning (Pan, Novembre, Song, Li, & Hu, 2018).

The social and memory studies mentioned thus far that used real-life strategies have mainly addressed the situation-dependent factor by using more contextualized environments or real interactions and daily events. Yet studies that have addressed the person-dependent limitation and the examination of freely moving participants are scarce. To address the issue of both mobility and context, Griffiths et al. (2016) recently examined participants while they were presented with a series of words to memorize along a predesignated route across campus while a mobile EEG system acquired ongoing neural activity. The paradigm they used allowed both free movement and real-world context. In line with previous lab-based studies, the authors identified significant low- to mid-frequency power decreases (< 30 Hz) over the left IFG. Critically, the authors reported that items strongly bound to spatial context exhibited significantly greater decreases in theta power than items strongly bound to temporal context, further highlighting the involvement of contextual factors in memory formation.

Note that newly available portable eye-tracking systems offer a cost-effective, easy to apply, and reliable measure of eye gaze and saccades in an ecological environment. Portable eye-tracking systems allow measuring numerous physiological markers that contain covert information about the cognitive state of a freely moving participant, including pupil dilation, eye movements, and fixations (Grace, Stanford, Gentall, & Rolan, 2010). Furthermore, tracking body motion by assessing whole-body or specific organ movements (e.g., head, shoulders, legs) may allow measuring

additional unconscious dimensions of behavior. For example, tracking the movement of two participants simultaneously allows measuring behavioral synchrony in an objective automated and ecological manner. Nonverbal synchrony can serve as an indicator of different aspects of social interaction (Hove & Risen, 2009; Ramseyer & Tschacher, 2011; Yun, Watanabe, & Shimojo, 2012). Bernieri and Rosenthal (1991) suggested that the degree of rapport between people is reflected by the behavioral synchrony between them.

Ramseyer and Tschacher (2011) analyzed videos of therapist-client sessions using an automated and objective video analysis method to calculate nonverbal synchrony. In their study, synchrony was shown to be positively correlated with the quality of the relationship as rated by the patient as well as with the patient's own sense of high self-efficacy. Thus, measuring movements in dyads provides interesting information regarding social interactions. Physical proximity to others has been shown to be a reliable indicator of underlying affiliative relationships feelings of comfort and safety with others (Cohen et al., 2017; Feeney, 1999). Thus, the portable eye-tracking systems and motion-tracking systems may be supplemented by other behavioral measures (interview, rating scales, microcoding of observers), autonomic systems activity, and brain signals (EEG, fNIRS). Combining multiple systems in real-life paradigms may unveil the physiological and neural underpinnings of behaviors fundamental to the human experience-natural behaviors in real-life situations.

It should be noted that although real-life paradigms enhance ecological validity, they pose serious challenges of controllability and reproducibility of involved stimuli and experimental conditions. The obvious trade-off between highly reductionist approaches that favor the fragmenting of everyday experiences to study the building blocks of cognitive functions and behavior versus the multidimensionality of real-life experiences is emphasized in this sense. Naturally, to address research questions studied in real-life settings, one should be careful to remove or control for sources of noise that relate to the nature of the environment, which is typically much richer and cluttered than in lab settings.

To enable insights as to the neural mechanisms that underlie cognitive functions in naturalistic environments such as movies, stories, and navigation, researchers are proposing new analysis techniques for neuroimaging data. One such approach involves tracking the shared sources of variance in measured responses across participants, a method that is particularly useful for stimuli that are not easily separable into discrete segments, such as stories or movies (e.g., Hasson et al., 2004). Analysis schemes that have recently gained popularity involve multivariate analysis algorithms. Such

analyses, the most popular of which use machine-learning classifiers, aim to reveal spatial patterns of activity that uncover collective representations of information (Cohen et al., 2017). The main advantage of multivariate analysis methods over univariate tests that treat each spatial unit independently (e.g., voxels) is in their ability to detect functional states of large-scale areas by hidden patterns of activation across functional units (Lewis-Peacock & Norman, 2013; Spiers & Maguire, 2007). Such methods, which can be applied to various imaging techniques (Jafarpour, Barnes, Fuentemilla, Duzel, & Penny, 2013; King & Dehaene, 2014), are particularly suitable for experiments involving rich, naturalistic settings because they may detect activation patterns that would not necessarily be revealed by model-based approaches (Maguire, 2012; Naselaris, Kay, Nishimoto, & Gallant, 2011).

To conclude, we show here that the amount of research and the number of scientists conducting research with real-life paradigms has significantly increased in recent years. Several exciting lines of studies in all fields of neuroscience are providing new discoveries, generating original ideas, and challenging longstanding conceptions of existing data collected from sterile lab settings. On the basis of these studies, we advocate in favor of a paradigm shift toward combining ecological setups with advanced portable neuro-behavioral recording devices that will enable the exploration of fundamental issues in naturalistic human behavior and cognition. We argue that studying the brain in real-life settings while accounting for person- and context-dependent issues may radically update our research questions and derived working hypotheses while retaining high standards of controllability and reproducibility.

Already more than a half a century ago, Brunswik argued that behavior observed in a constrained environment can speak only to behavior in that particular environment. Nevertheless, real-life paradigms pose real challenges in the analysis and interpretation of stimulus-response relationship, owing to the complex statistical properties of natural stimuli. Prima facie testing cognitive functions in real life is seemingly impossible. Nonetheless, compared with simple stimuli, real-life paradigms require fewer a priori assumptions regarding relevant stimulus parameters. To meet this challenge, it is necessary to establish suitable environmental settings, apply portable measuring devices of movement and eye gaze, and record autonomic responses and neural activity, collectively enabling the construction of controlled and reproducible experimental designs for studying human cognition in natural settings. This approach puts forward exciting avenues for studying psychological questions in an ecologically natural platform that are necessary for making the next leap in

understanding neural mechanisms underlying social, cognitive, and emotional effects within the context in which these behaviors actually take place.

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