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ORIGINAL ARTICLE

Theorizing Flow and Media Enjoyment as Cognitive Synchronization of Attentional and Reward Networks

René Weber[1], Ron Tamborini[2], Amber Westcott-Baker[1], & Benjamin Kantor[1]

1 Department of Communication, University of California Santa Barbara, CA 93106-4020, USA
2 Department of Communication, Michigan State University, Michigan 48824-1212, USA

This article reconceptualizes the psychological concept of "flow" as it pertains to media entertainment. Our goal is to advance flow theory in ways that highlight the necessity of reliable and valid operationalization. We posit flow as a discrete, energetically optimized, and gratifying experience resulting from a cognitive synchronization of specific attentional and reward networks under condition of balance between challenge and skill. We identify video-game play as a context in which flow is likely to occur, and where we can observe our neurophysiological conceptualization of flow using measurement techniques (functional magnetic resonance imaging [fMRI]) without disrupting the experiential state. After presenting preliminary evidence consistent with our synchronization theory of flow, we suggest ways to advance this research.

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This article suggests a reconceptualization of the psychological concept of flow as it pertains to mediated experiences. We specifically aim to further flow theory as applied to media entertainment in ways that highlight the necessity of reliable and valid operationalizations and measurements. The concept of flow originates in Csikszentmihalyi's (1990) theory of human happiness, balance, and optimal experience. Its original formulation posits that an experience, such as media enjoyment, can be viewed as the source of *flow states*, which are characterized by intense attentional focus, pleasurable feelings, and emotional rewards. This article will argue that in the media context, flow can be viewed as a discrete, energetically optimized, and gratifying experience resulting from a cognitive synchronization of attentional and reward networks under condition of balance between challenge and skill. This concept of flow as a cognitive-synchronization process provides, for the first time, both a theoretical rationale for this concept and a direct measurement of flow states.

Corresponding author: René Weber; e-mail: renew@comm.ucsb.edu

Meta-theory and foundations

On a meta-level, our theorizing is based on the neurophysiological perspective (NPP) in communication research, which has been proposed as a way of expanding upon and informing existing theory and research in light of current scientific perspectives (Weber, Sherry, & Mathiak, 2008). The NPP advocates looking for biological and evolutionary explanations for historically recognized relationships between variables in order to parse out the existing theories of communication, allowing continuing research to focus on fewer and more powerful theories. The NPP shares some basic assumptions with existing work in the communibiological paradigm (cf. Beatty & McCroskey, 2001) in that both emphasize the role of neural explanations of observed communication behaviors. The NPP, however, is strongly rooted in systems theory and constitutive reductionism (Sarkar, 1992) in contrast to substitutionism or eliminative reductionism. The NPP advocates a systemic approach to investigating the parts to better understand the whole, and values data derived from different levels of analysis. The perspective suggests the inclusion of biological determinants that are embedded in a complex system of nature–nurture interactions (cf. Sherry, 2004a) in order to inspire theorizing in the communication sciences.

Applied to the context of interactive media, our proposition is based on theory and research found in the entertainment literature. The study of flow in the context of media use in general and video-game play in particular has been a recent focus among communication scholars engaged in research on media entertainment (e.g., Bryce & Rutter, 2001; Finneran & Zhang, 2003; Mandryk, Inkpen, & Calvert, 2006; Rheinberg & Vollmeyer, 2003; Sherry, 2004b; Weibel, Wissmath, Habegger, Steiner, & Groner, 2007). Sherry (2004b) identified the importance of flow theory by arguing it could be used to address shortcomings in entertainment theory regarding what it means to "enjoy" media and why people spend so much time pursuing entertainment. We argue that this is particularly true for video games, and that video games are unique in their opportunity for the balance between challenge and skill that can stimulate the neural processes responsible for flow. Similarly, Sherry's (2004b) discussion of flow focused on the ability of media use to satisfy intrinsic motivations related to the balance of challenge and skill, and how the gratifications derived from this balance could be labeled "enjoyment." His treatment showed the value of applying flow to the study of video games and other media by noting flow's ability to account for contradictions in existing entertainment research. At the same time, Sherry's uses and gratification focus left some aspects of flow's connection to enjoyment unformulated. Questions about the conception of flow have been raised by several media scholars, who ask if flow as defined by Csikszentmihalyi (1988) needs to be reassessed for its application to media research (e.g., Finneran & Zhang, 2003; Rheinberg, Vollmeyer, & Engeser, 2003). Although we consider it greatly ill advised to reconceptualize flow specifically for media research, these types of concerns may point to the need for more explicit accounts of flow that would enable scholars to understand the phenomenon more clearly across media and other domains.

Our proposition provides a neurophysiological account of flow, intended to eliminate what we see as conceptual ambiguity related to flow experiences in media environments. Moreover, the conceptual precision of this neurophysiological account points to specific measures that enhance operational clarity. Most other accounts of flow have limited themselves to describing an experience at the level of qualia, that is, phenomenal aspects of our mental lives that are introspectively accessible. Yet, flow is said to occur at an unconscious level of awareness, making the experience difficult if not impossible to distinguish by recollection (Csikszentmihalyi, 1988). Our article defines flow as the conscious awareness of positive affect that results from an intrinsically rewarding (unconscious) synchronization of attentional and reward neural networks, and suggests ways to delineate this neurophysiological response. We use a limited-capacity model of attention (Lang, 2000, 2006; Lang & Basil, 1998) to explain flow as an attentional phenomenon, linked to the concept of available attentional resources. The experience we describe can occur in both mediated and nonmediated environments; however, we focus on media experience. Below we will elucidate how we reconceptualize flow as a cognitive network synchronization process, but first we will provide a background on flow theory, its uses in the media enjoyment literature, and its unique applications to playing video games.

Flow theory: A primer

Flow theory, originally advanced in the 1960s as an explanation of the enjoyment derived from everyday activities, was developed out of a desire to understand creative experiences and the motives for engaging in them. As it gained popularity, flow theory came to describe a much broader paradigm of how individuals subjectively experience intrinsically motivating enjoyment (Nakamura & Csikszentmihalyi, 2002). Drawing on research about intrinsic motivations, the theory has attempted to describe the conditions of ideal happiness or ''optimal experiences'' derived through absorption with a challenging task. Over the years, flow theory became incorporated into the field of psychology within the humanistic tradition of Maslow and Rogers (McAdams, 1990), and gained support through empirical studies in motivation and self-determination theory as researchers looked to explain motivation beyond the dominant paradigms of reinforcement-based and ''drive'' theories (Deci, 1992).

Within communication research specifically, flow theory has been used to explain media choice or enjoyment. Yet methodological difficulties in measuring flow have hampered further discovery in processes of flow states (Nakamura & Csikszentmihalyi, 2002). Our discussion of flow and its applications to understanding media will directly address this challenge. We follow a path from the theory's originator, Mihaly Csikszentmihalyi, through its innovative application to media enjoyment by John Sherry (2004b), to its neurophysiological antecedents and measures proposed by Arne Dietrich (2004).

Csikszentmihalyi's concept of flow

Csikszentmihalyi described flow as a discrete state of human experience in which one's potential is realized through a specific activity that demands an optimal amount of individual resources. Flow is thus characterized by traits including: (a) a sense that one's skills are balanced with the challenge presented; (b) intense concentration such that "there is no attention left over to think about anything irrelevant," (c) the disappearance of self-centeredness and the transformation into a state of holistic consciousness; (d) the distortion of time; (e) the pleasantness of the experience, which is not perceived as taxing, and (f) the gratification such that an individual would perform the given activity "for its own sake, with little concern for what they will get out of it, even when it is difficult, or dangerous" (Csikszentmihalyi, 1990, p. 71).

Key to our understanding is the intense concentration characteristic of flow and intrinsic enjoyment, concepts that neurological research has shown to be closely related (Hamilton, 1984). The intense focus characteristic of flow experiences has also led some to use meditation as a rhetorical tool for the purposes of analogy, whereas others have looked at meditative experience as a potential context for studying flow (Massimini, Csikszentmihalyi, & Delle Fave, 1988; Newberg & Iversen, 2003).

This intense, absorptive attention that characterizes flow is likely related to another consequence associated with flow experiences: The distortion of time. When one is experiencing flow in a manner such that awareness of external stimuli (or even the internal stimuli that constitute the self) is almost entirely eliminated, it is apparent that the individual's perceptions of time would temporarily be altered. This effect is because of the full absorption of attentional resources during flow states—the "normal" capacities for experience of time and self are so far surpassed by the requirements of generating flow that "the clock no longer serves as a good analog of the temporal quality of the experience" (Csikszentmihalyi, 1988, p. 33).

Thus, attention is a vital component to the conceptualization of the self from which Csikszentmihalyi's flow theory emerged—the allocation of attentional resources is central to flow theory. Attention is "the medium that makes information appear in consciousness" (Csikszentmihalyi, 1988, p. 17). In its capacity of highlighting what is available to the self, attention is conceptualized as one of the three functional subsystems of evolved consciousness, along with awareness and memory (Broadbent, 1958). Csikszentmihalyi (1988) subscribes to Kahneman's (1973) notion of attention as "psychic energy," or a finite resource spent on any nonreflex task.

Media enjoyment as flow experience

Media settings requiring explicit attention and thought are believed to be well suited for providing balance between challenge and skill, the antecedent conditions necessary to produce resource-allocation demands conducive to the production of flow.[1] Video games are particularly conducive to eliciting this type of balance and resulting flow experience. As Sherry (2004b) asserts: "Some might comment that Csikszentmihalyi seemed to have video games in mind when he developed the concept of flow" (p. 339), noting that "[video] games possess ideal characteristics to create and maintain flow experiences in that the flow experience of video games is brought on when the skills of the player match the difficulty of the game" (p. 340). It is no small coincidence that these conditions are well met by and found in media experiences that we label as *entertainment*. As such, not only do we think that media provide a good setting in which to examine the processes posited to produce the phenomenon of flow as we define it theoretically, but we feel that our conception of flow is particularly important for entertainment theorists interested in understanding the "enjoyment" or reward of certain media experiences that cannot easily be explained by traditional narrative theories of media entertainment.

Sherry's (2004b) previous work on flow hypothesized that the theory could be used to explain enjoyment of media content, in that media use is clearly capable of bringing about three marking features of flow experiences: (a) intense focus and loss of self-consciousness, (b) highly enjoyable experience, and (c) temporal distortion. Sherry's use of flow theory here does not specifically deal with the attentional aspect of flow experiences. Beyond its initial mention as one of the criteria used in assessing the validity of media exposure as a flow-producing activity, attention is conceptually overlooked. However, Sherry does elaborate a compelling case for the mapping of flow's challenge/skill proposition onto media use, and his discussion of challenge and skill highlights features of video-game technology that makes it ideally suited for experiencing flow, distinguishing the antecedents of active flow from the more passive states.

Csikszentmihalyi's focus on challenge and skill evolved from early research on play and the relationship between the difficulty of play tasks and the individual's ability to perform those tasks (Csikszentmihalyi & Bennett, 1971), leading to the idea that flow results directly from a balance between a challenge and skill (Csikszentmihalyi, 1997). Sherry (2004b) details this balance in a model designed to show how flow can occur at different levels of escalating challenge, as long as that increased challenge is accompanied by a matched increase in skill.

The notion of balance between challenge and skill, at an intuitive level, is the sense that one's ability is sufficient to perform a given task. The conscious awareness of a balance between skill and challenge is associated with the feeling of competence (Mitchell, 1988). At a cognitive level, we might think of this balance in terms of *mental models*, which are cognitive constructions that represent our understanding of some particular aspect of the world (Sowa, 1984). They are simplified representations of how things work, and by nature are easily changed through encounters that provide new experiences from which to learn (Dix, Finlay, Abowd, & Beale, 1993; Norman, 1983). In the context of video-game play, *skill* can be thought of as how accurately an individual's mental models represent embedded game rules and the mechanics of how toggles or keypads manipulate virtual environments. The acquisition of these mental-model skills is necessary to "control" the game world and play well. Possessing the mental models necessary to manipulate a game can be understood as responsible for feelings of competence accompanying video-game flow states.

To help in the acquisition of requisite skills, games are designed with features to quickly teach users new mental models (Gee, 2007; Shaffer, 2006). These features support continued development of game-related skills needed at higher levels of difficulty. This combination of increasing game difficulty matched with the cultivation of requisite mental models offers an environment of constant balance between escalating challenge and skills, perfectly suited for extended flow experiences. Moreover, not only do games create these environments, but they do this in a manner that promotes the principles of practice and repetition central to any learning process (Bransford, Brown, & Cocking, 1999). Hence, players should learn that certain game environments are capable of activating this innately rewarding experience of bound attentional networks.

Of course, it is evident that users also develop mental models in other linear/narrative entertainment media (Sherry, 2004b), yet this occurs in a more limited manner. Both games and linear media such as books and film require users to develop mental models of characters, objects, events, and the narrative account that connects them in order for the user to understand the story. In this sense, the development of skills is well enough matched to the challenge of understanding sophisticated narratives to appreciate the experience; yet, the wide ranging set of complex skills needed to play games is not necessary for these experiences. There is no real sense of "control" over these environments as there is with video games.

A critical view on the application of flow and related concepts in media research

Research on flow has been applied in a variety of media contexts such as during Internet use (Chen, 2000; Chen, Wigand, & Nilan, 1999, 2000), in computer-mediated environments (Finneran & Zhang, 2002, 2003; Ghani, 1995; Ghani & Deshpande, 1994; Siekpe, 1995; Trevino & Webster, 1992; Webster, Trevino, & Ryan, 1993), and in online consumer behavior (Koufaris, 2002). Bryce and Rutter (2001) applied flow perspectives to video-game play in particular, suggesting that the psychological dimensions of gaming seem similar to the experience of flow. Flow-related experiences have been studied directly in experiments observing play using game consoles (Bowman & Boyan, 2008; Bowman & Sherry, 2006; Mandryk et al., 2006; Sherry, Rosaen, Bowman, & Huh, 2006) as well as play online (Rheinberg & Vollmeyer, 2003; Weibel et al., 2007). As pointed out earlier, Sherry (2004b) argues that the flow model is particularly well suited to studying new media such as video-game technology. However, this position has not gone unchallenged. The increased attention to flow in interactive environments led Finneran and Zhang (2003) to question whether flow, as defined by Csikszentmihalyi, was appropriate for research in this context. They argued that the concept of flow needed to be closely reevaluated before it was applied to computer-mediated experience. Their own reconsideration led to a revised model of flow, integrating characteristics of the user, the task, and artifacts of different media technology that were thought to determine flow experience. A similar model has been recently applied to research using video games (Cowley, Charles, Black, & Hickey, 2006).

Much of the confusion about flow centers on issues related to how flow has been measured. In a review of research on flow in mediated environments, Novak, Hoffman, and Yung (2000) identify at least 13 separate constructs used to study flow, with different combinations of these constructs appearing in different investigations. Rheinberg and his colleagues (Rheinberg, Vollmeyer, & Engeser, 2002; Rheinberg et al., 2003) used factor analysis to collapse many of the traditional characteristics of flow into two dimensions labeled *absorption* (involvement, distorted sense of time, optimal challenge, absent-mindedness) and *smooth and automatic running* (e.g., concentration and focus, control, clarity, and smooth and automatic thought). Although the two factors were said to account for most of the variance in flow experience and offer a simplified understanding of the construct, this conclusion has done little to resolve confusion.

Adding to the confusion over classification is the fact that all definitions of flow describe a concept that cannot be examined directly, and research based on these definitions use various methodological approaches to observe it. Early research focusing on flow in daily life used the experience sampling method (ESM) with the hope that observation in natural environments would help overcome ecological validity problems often associated with retrospective recall (Csikszentmihalyi, Rathunde, & Whalen, 1997). The ESM sent signals periodically to respondents over a period of weeks, directing them to complete a survey reporting on their present activity and experiential state (Csikszentmihalyi, 1988). Although the ESM provided a dynamic view of flow in daily life, the relatively low likelihood of a specific flow experience occurring when the signal was sent made the ESM an impractical tool for studying the actual flow experience deeply.

Growing interest in flow occurrences during computer-generated experience inspired several different methodological approaches, each with their own limitations. Finneran and Zhang (2002) reviewed some of these approaches, providing detailed critiques of naturalistic signal-contingent or event-contingent methods that use self-report, of nonsituated surveys that measure generalized computer-generated experience, of experimental approaches, and qualitative techniques such as protocol analysis. For example, they note how Chen and Nilan (1998) adapted the ESM to study Web browsing by installing pop-up measures that appeared regularly during use, in hopes of remaining natural while allowing the observation of specific media activity; and how Wheeler and Reis (1991) advocated the use of an event-contingent method in which respondents self-report after the occurrence of a specific event in order to measure efficiently only at times when events occur. They point out that though both methods have advantages, each relies on the subjects' commitment and ability to accurately report their activities and experiential states. They criticize nonsituated surveys that use closed-ended questions and ask respondents to evaluate general cases instead of a specific experience, describing these approaches incapable of accounting for the complex and dynamic nature of flow; and they challenge the external validity of experiments, holding that the context-specific nature of flow might not be replicated in controlled-media environments. As a rule, they call for assessment in real time, with measures at multiple time points to allow observation of both the actual flow experience and the manner in which it changes. Of course, multiple-point, real-time measurement does not assure accurate assessment.

Finneran and Zhang (2002) join Nakamura and Csikszentmihalyi (2002) in noting the even greater difficulties associated with operationally defining dimensions of flow. Because flow is conceptually defined with vague terminology, it is not surprising that efforts to operationally define flow have taken various approaches and produced a set of findings that are incongruous and sometimes contrasting. Not only do researchers have a difficult time agreeing on which dimensions should be included as part of the measure of flow, but problems are caused by issues regarding the theoretical weights of each of the included dimensions and the fact that many of these dimensions themselves are thought to be multifaceted. The commonly found use of single-item and unidimensional scales has created great concern with regard to measurement validity (Finneran & Zhang, 2002).

Undoubtedly, much of the confusion associated with observations of flow results from challenges associated with using self-report techniques to measure experience governed by activity in implicit systems that is inaccessible to conscious awareness. Because it is difficult for humans to accurately attribute the source of positive affect to a complex neurological state, self-reported accounts of flow experience have produced descriptions characterizing it in terms of easily identifiable correlates that often accompany the experience, such as feeling alert, a sense of control, and a distorted sense of time (Csikszentmihalyi, 1997). Yet, even this simplified approach has proven difficult to apply successfully. These difficulties are evident in the great frequency with which respondents answer "I don't understand" to questions on posthoc flow questionnaires, such as those designed to measure the "feeling of positive challenge" associated with flow (Chen et al., 1999). All of this has led to an amalgamation of models and operational procedures used to study flow in which the sequence of antecedents and consequences is often difficult to untangle. What is considered a precursor in one study is regarded as the flow state itself in another.

We hope to overcome these problems by defining flow as the synchronization of specialized attentional and reward (limbic) neural networks, and by offering a means of directly observing this coordinated activity in using dynamic real-time measurement techniques that allow observation of both the actual flow experience and the manner in which it changes.

Dietrich's neurocognitive concept of flow

Dietrich (2004) presents an explanation of flow experiences firmly rooted in cognitive neuroscience. His description of the neural correlates of flow relies on the implicit/explicit distinction with regard to information processing. The explicit system is rule-governed, expressible through verbal communication, and part of the conscious awareness, whereas the implicit system is skill- or experience-based, inaccessible to conscious awareness and cannot be expressed outside of task performance (Dietrich, 2004).

Dietrich (2004) contends that optimal performance, consistent with Csikszentmihalyi's conception of flow, is associated with maximized implicitness, which occurs through practice and experience. Highly practiced explicit skills can, with time, pass into implicitness. Owing to the connection between the prefrontal regions of the brain and explicit processing, Dietrich deems this condition of suppression "transient hypofrontality"—the notion of reduced activation in the frontal (and especially prefrontal) cortex—also noting that "flow experience must occur during ... the inhibition of the explicit system" (p. 757).

Although Dietrich's explanation of the flow phenomenon is a feasible, if basic, neurocognitive conception that makes an earnest attempt to describe a construct previously defined in psychological terms with the aid of cognitive science and neuroscientific knowledge, it oversimplifies the operationalization of flow experiences. Moreover, Dietrich's notion of hypofrontality stands in sharp contrast to understanding flow as a state of focused attention. Multiple functional magnetic resonance imaging (fMRI) studies that have identified attentional networks (see below) provide convincing evidence for increased rather than reduced activity in involved prefrontal networks during states of focused (cf. Raz & Buhle, 2006), meditation-like (Newberg & Iversen, 2003) attention. It has to be mentioned, however, that Dietrich's assumptions are based solely on a compilation of diverse empirical evidence that is largely independent of a specific flow experience and does not consider attentional tasks related to flow. In contrast, our proposition is strongly based both on flow theory and on prior evidence within the cognitive neuroscience of attention—one of the most comprehensively studied fields within the cognitive sciences (cf. Raz & Buhle, 2006). Despite some differences, both Dietrich's attempt and ours further efforts to distinguish flow as a specific and distinct concept within a testable, measurable framework enabled by the theories and tools of both cognitive communication science and cognitive neuroscience.

Attention—A multidimensional concept

Attention is one of the most studied cognitive processes in the social sciences. It is also one of the most difficult to define. It seems that the more information we gather about how the mind and the body work, the farther we get from concrete, consolidated definitions of the attention construct and its component parts (Lang & Basil, 1998; Raz & Buhle, 2006). Consequently, there is no single "textbook" definition of attention, but it is largely conceptualized as the means by which the brain chooses information (sensory or from previously formed mental representations) for further processing (Banich, 2004). In the following paragraphs, we present attention as an important concept within the field of communication. Thereafter, we present its roots within the cognitive neurosciences. Finally, we discuss the prominent tripartite theory of attention (Posner, Inhoff, Friedrich, & Cohen, 1987) and its importance for our reconceptualization of flow.

The concept of attention has occupied a place of prominence in the communication sciences, especially as a means of apportioning cognitive resources to engage in communication or to attend to media messages (Reeves, Thorson, & Schleuder, 1986). In particular, Lang's (2000, 2006) limited-capacity model of motivated message processing (LC4MP) includes three processes—encoding, storage, and retrieval—the first of which largely involves attention as a means of choosing information to be stored. Other communication theories (e.g., selective exposure theory with its notion of messages' intervention potential; cf. Bryant & Zillmann, 1977) have implicitly and explicitly used attention as a concept (for an overview, see Anderson & Kirkorian, 2006; Lang & Basil, 1998).

Meanwhile, it is well established in the cognitive sciences that attention is multidimensional (for a review on the history of investigating attention, cf. Raz & Buhle, 2006). Early neurophysiological work by Mesulam (1981) and others laid the foundation for a network-based conception of attention, meaning that the areas of the brain that engage in attentional processes are distributed over the brain, working together simultaneously. Posner et al.'s (1987) influential tripartite theory of attention has sparked further discoveries about the nature of attentional processes. Specifically, Posner proposed and provided strong empirical evidence for a three-network view of attention involving alerting, orienting, and executive processes (Posner et al., 1987; cf. Raz & Buhle, 2006). Alerting—also known as sustained attention, vigilance, and alertness—is the ability to strengthen and maintain "response readiness in preparation for an impending stimulus" (Raz & Buhle, 2006, p. 371). Orienting (or scanning/selection) is the ability to choose incoming sensory information to which to attend (Lang, 2000; Lynn, 1966). Executive attention is perhaps the most "conscious" type of attention, and involves "planning or decision making, error detection, . . ., regulation of thoughts and feelings, and overcoming of habitual actions" (Raz & Buhle, 2006, p. 374).

It is still a matter of debate as to whether these component processes are independent from one another or whether activity in one portion directly affects activity in another. Although all three attentional networks are complex in nature, executive attention is still the least understood and involves multiple other cognitive functions. However, methodological advances over the past two decades in cognitive psychology and neuroscience have allowed major discoveries as to the physiological components of these attentional networks.

For the purpose of this article, we focus on alerting and orienting, the first two of Posner's (and others, cf. Fan, McCandliss, Fossella, Flombaum, & Posner, 2005) attentional networks, which should not suggest that executive networks are less meaningful for the conceptualization of flow. The alerting and orienting networks have great relevance here because they largely correspond with particular neurological regions of interest (in contrast to executive attentional networks); in a simplistic sense, the alerting network consists of frontal and parietal cortical regions, and is used to achieve and maintain an alert state. The orienting network consists of superior and inferior parietal lobe regions, the frontal eye fields, and the superior colliculus (cf. Fan, McCandliss, Sommer, Raz, & Posner, 2002). However, before discussing the dynamics of these networks in relation to flow experiences, we should first address the nature of network synchronization with the illustrative example of its most studied phenomenon, cognitive binding.

Network synchronization and cognitive binding

Synchronization of neural networks has been a well-investigated phenomenon in the past two decades, but is only now beginning to be understood theoretically. Some of the earliest theories about the phenomenon posit it as a solution to what is widely referred to as the *binding problem* (cf. Crick & Koch, 1990; Garson, 2001; Stryker, 1989; Ward, 2003). Early theories of visual object-recognition and memory hypothesized neurons as the building blocks of brain function such that an individual neuron would respond to discrete objects. Among the problems with this ‘‘grandmother cell theory’’ (so called because an individual would have a unique neuron that fires upon seeing a specific person, such as a grandmother) is the vast number of cells that would be required to represent every possible object or perception, from every possible angle, and in every possible area within one’s field of vision. Today, we know that this is largely not the case. A great deal of processing in the brain and visual sensory system is localized by function with neurons responding not to entire objects, but to properties such as color, texture, line orientation, etc. However, when we consider this localization of function, the binding problem becomes clear: How does an individual perceive different properties of an apple not *separately* as red, round, in a certain location, and of a certain size, but as a discrete object? How does the brain put the perceptual pieces back together when different networks of the brain are ‘‘seeing’’ the redness, roundness, etc.?

One prominent theory about how the brain binds different processes together into a single, conscious experience involves the mechanism of neuronal oscillatory synchronization (cf. Buzsáki, 2006). Neurons oscillate when they ‘‘fire’’ at a regular rate, measured in hertz (Hz). The firing rate can be determined according to their fast action potential or their postsynaptic potential (for a review of oscillatory neuron activity, see Ward, 2003). These oscillations correspond to the familiar alpha, beta, gamma, delta, and theta waves that cognitive psychologists have studied for the last century. Most binding theories and investigations involve gamma waves (approximately 40–60 Hz), though recent work has increasingly looked into other wave types (cf. Başar, Başar-Eroglu, Karakaş, & Schürmann, 2001; Steriade, Gloor, Linás, Lopes da Silva, & Mesulam, 1990). Given that groups of neurons are activated in periodic patterns, synchronization can be understood as ‘‘a state in which two or more oscillators display the same frequency because of some form of co-interaction’’ (Steriade et al., 1990, p. 481); that is, two or more groups of neurons oscillate at the same frequency. This network synchronization is conceptualized as a means of feature binding by virtue of its ability to transiently link neurons or groups of neurons. Regarding visual attention, for example, we know that representations of the various visual properties of an object are combined transiently in the brain, making the conjoint output of different property-specific detectors available to higher-order mechanisms for perception and action (cf. Stryker, 1989). Thus, the properties of the red, round apple are combined via oscillations of the neurons detecting the redness, the roundness, etc., and perceived by the conscious mind as a single object.

Binding, synchronization, and holistic experience

Individual cell oscillations have been measured via single-cell electrodes or multiunit electrodes implanted directly into the brain in nonhuman animals, and occasionally in humans prior to brain surgery. Early neurophysiological work on the perceptual binding of visual features drew upon these methodologies to study the visual cortex in cats and found evidence of synchronized gamma oscillations as a mechanism of feature binding in visual perception (Eckhorn et al., 1988; Gray & Singer, 1988).

Later developments of the neuronal oscillation theory of binding recognized that more processes in the brain involve a binding of disparate functions together than simply object perception. Crick and Koch (1990), for example, distinguished between three types of binding: (a) biologically/neuronally prebound items or concepts, which really are "grandmother cells" (see above) or whose synaptic connections are innate; (b) "overlearnt" bindings, in which there exist synaptic connections that were forged through learning; and (c) transient binding, which is "neither epigenetically determined nor overlearnt ... [this latter] binding must arise rapidly ... and must have almost unlimited potential capacity, although its capacity at any one time may be limited" (p. 269). Transient binding is the type linked with neuronal oscillations—while few concepts or processes can have their "own" neurons or innate networks, and a larger but still limited number can have forged synaptic links, nearly infinite neuronal combinations can be made transiently through some means of interneuronal communication such as synchronized oscillations. Interestingly, Crick and Koch (1990) suggested that synchronized gamma oscillations are not only a mechanism for perceptual binding, but for conscious awareness of information, working memory, and attention. "The likelihood that only a few simultaneous, distinct oscillations can exist happily together might explain, in a very natural way, the well-known limited-capacity of the attentional system" (p. 272; see also Lang, 2000). In fact, gamma oscillations have been linked with attentional processing, and alpha oscillations are associated with attentional suppression (Ward, 2003).

Klemm, Li, and Hernandez (2000) also distinguished between perceptual binding and other types of cognitive binding: "cognitive binding consists of a set of functions involving *registration* of sensory information or endogenous thought pattern, *interpretation* of alternative meanings or solutions (some of which reside in memory), *decision* or problem solution, and *recalling* the task long enough to consciously realize and report it" (pp. 66–67). They found evidence of gamma synchronization in ambiguous-figure tasks at the moment when the alternative figure was recognized (or "bound"). They hypothesized that different frequencies may represent different components of cognitive binding of brain functions.

In fact, it seems likely that oscillatory network synchronization is an answer not only to the binding problem, but also to the problem of how the actions of individual neurons emerge into ''whole-brain-work'' (Başar, 2006). The results of multiple branches of research suggest that neuron oscillations and their synchrony do not have a single purpose, but can be seen as performing multifold functions in brain activity, each determined by a multitude of factors that include the ''frequency, enhancement, time locking, phase locking, delay, and prolongation of the oscillation'' (Başar et al., 2001, p. 246). Synchronous oscillation may be the primary means by which individual neurons and networks of neurons communicate with each other, both by modulation (von der Malsburg & Schneider, 1986) and by propagation because of resonance (Başar, Başar-Eroglu, Karakaş, & Schürmann, 1999). And it may well be that cognitive binding and network synchronization is the key to a better understanding of holistic, higher-order experiences that cannot be well explained by isolated traits of those experiences.

The cyclic nature of brain waves (and of nature in general; cf. Buzsáki, 2006) also provides a mechanism explaining the endurance of a state. Lisman and Idiart (1995) proposed a model of short-term memory as oscillatory activity that explains the classic ''7 ± 2'' items that can be held in short-term memory. In this model, items are ''refreshed'' in memory with each period of the oscillation. This conceptualization of brain waves as a mental refresh rate can be applied to other conscious and semiconscious experiences such as attention and perception, and, along with the previously mentioned limitation of the number of oscillations that can coexist within the brain at any one time, helps provide a basis for the limited resources of conscious brain functioning.

Synchronization as a discrete state

Important to our larger discussion is the notion that synchronized oscillations are discrete states, not a continuum. There are different types and functions of oscillations, but groups of neurons are either synchronized or not and the transition between a nonsynchronous and synchronous state occurs within a short time-window. Haken (2006) describes a synergetic theory of brain function where logical processes are nonlinear and contain some parameters of ''bistability''—that is, there are two possible stable states, and small variations cause a *qualitative* shift to one or the other. In this theoretical model, two (groups of) neurons oscillating on very different periods are qualitatively the same as two (groups of) neurons that are just barely out of sync, but synchronization leads to a phenomenon that is qualitatively different. Haken describes that the brain ''operates close to instabilities and achieves its activity by self-organization which leads to the emergence of new qualities'' (p. 110).

But why are synchronized oscillations discrete states and do not define a continuum? Here, we refer to a concept that originates in statistical physics: The concept of self-organized criticality (SOC). SOC was first identified by Bak, Tang, and Wiesenfeld (1987) and is considered to be one of the major discoveries in statistical physics. It describes a mechanism by which complexity arises in nature and has been found to exist in a wide variety of dynamic systems (for a review, see Eliasmith & Anderson, 2003). The classic simulation for characterizing SOC is the "Bak Sand Pile Model" (Bak et al., 1987). In this demonstration, a sand pile is built one grain at a time. As each grain drops onto the structure, some existing components of the sand pile are displaced. These displaced grains are variable, but are typically small in number. However, at critical time intervals single grains of sand can trigger sudden, large-scale displacements, termed *cascades* or avalanches, which fundamentally alter the structure and dynamics of the system. A notable example of cascades in the context of complex functional networks is in the work of Beggs and Plenz (2003), who found empirical evidence for the existence of neuronal network cascades in the course of behavioral activity. This important piece of evidence in combination with the general concept of SOC in natural systems may explain why synchronized oscillations define discrete states and not a continuum. We will refer to this notion below when we present our "Synchronization Theory of Flow."

Pleasure and reward in the brain

As explained above, one of the key characteristics of a flow experience is its pleasantness and gratification for an individual. Thus, our discussion will now turn to the current understanding of pleasure and reward from an NPP.

As with most cognitive and experiential phenomena, pleasure and reward do not take place within any single area of the brain, but rather are mediated by a complex network of interconnected structures. It is debatable whether cognitively complex behaviors that are perceived as rewarding (e.g., watching a movie or playing a video game) are mediated by different cognitive processes and structures than the rewards stemming from basic drives such as food, water, and sexual behavior. However, much of the research on reward in the brain is based on human or animal studies of the more basic-drive types of rewards (cf. Baldo & Kelley, 2007), apart from some recent studies that have looked into more abstract rewards such as monetary gain or social competition (cf. Eddington, Dolcos, Calbeza, Krishnan, & Srauman, 2007; Fliessbach et al., 2007; Frackowiak et al., 2003). A complete review of the structures involved in reward and pleasure is outside the scope of this article, but the structures most relevant to our discussion include the dopaminergic system, the orbitofrontal cortex, the ventromedial and dorsolateral regions of the prefrontal cortex, the thalamus, and the striatum.

The hypothesized roles of these structures in the experience of reward can be elucidated when reward is conceptualized as a process rather than a single state. Naturally motivated, and therefore rewarding, behaviors can be characterized as *appetitive* or *consummatory* (Pinel, 2005; see also Lang, 2006). Appetitive behaviors include those actions involved in seeking rewards, such as foraging for and hoarding food. Consummatory behaviors involve the actual act (consummation) of gaining the reward, and are usually associated with the pleasurable experience of the reward. Baldo and Kelley (2007) hypothesize a physiological difference implied by this distinction, as "behaviors during the appetitive phase are guided by internal representations of the goal (or expected characteristics of the goal), while the consummatory phase is influenced by the sensory feedback and internal signals accompanying actual commerce with the goal," suggesting that these behaviors "are governed by at least partially nonoverlapping neural substrates" (p. 446). Although dopamine transmission has largely been associated with reward for many decades, recent research has rejected dopamine's role in the hedonic pleasure (i.e., the "liking" aspect) of rewards that would take place during the consummatory act (Baldo & Kelley, 2007; Banich, 2004; Frackowiak et al., 2003). Instead, theories for dopamine's role in rewarding behavior include mediating incentives ("wanting") or predicting rewarding outcomes (Frackowiak et al., 2003), both of which would be linked to appetitive or reward-seeking experiences. Baldo and Kelley (2007) make a convincing argument by showing that lesions to dopaminergic regions do not affect consummatory behaviors. Other cortical regions that are also hypothesized to be involved in appetitive, reward-seeking behaviors include the medial temporal, dorsolateral, prefrontal, premotor, and orbitofrontal cortices. These regions are largely implicated in reward representation and goal detection (Frackowiak et al., 2003).

Much research suggests that the striatum is the main site of the actual pleasurable experience of rewards (Baldo & Kelley, 2007; Fliessbach et al., 2007; Frackowiak et al., 2003). The striatum is part of the basal ganglia, and as such part of the brain's limbic system. The basal ganglia are interconnected masses of gray matter located in the interior regions of the brain and in the upper part of the brainstem. Because of its central location and its function as an input nucleus for the basal ganglia, it is assumed that the striatum evolved very early in human development.

Baldo and Kelley (2007) review the evidence for a linkage between striatal opioid peptide release and the experience of reward during consummatory behavior. Perhaps most relevant to our discussion of flow is the apparent regulation of consummatory behavior by amino acid transmission in the nucleus accumbens shell. Baldo and Kelley hypothesize that the area acts to toggle behavior in and out of consummatory acts. They conceptualize the consummatory act as a discrete state where consummatory motor acts (such as biting, chewing, etc., during eating) are somewhat automatic. In fact, they describe animal studies in which cortical electroencephalography (EEG) patterns moving rapidly from nonsynchronized to synchronized upon initiating the consummatory act. Preliminary fMRI data from humans in a study involving thirst-quenching provide supporting evidence for alpha-, beta-, and theta-wave activity being involved in the experience of consummation (Hallschmid, Mölle, Fischer, & Born, 2002). These results imply that the experience of reward and attention, along with neural synchronization processes, are related in some crucial way.

The synchronization theory of flow

A brief recapitulation of the flow concept's characteristics may be helpful at this point. We discussed the experience of flow as a balance phenomenon, as an intense concentration that comes with the distortion of time, and as a pleasant, autotelic experience. Flow can be characterized as a state of holistic consciousness that is more than its parts. Flow during task performance is not perceived as taxing, although challenges that come with a task can be high. Flow states are perceived as highly rewarding. There is no continuous transition between a no-flow state and flow state—transitions are sudden, from one moment to the other, and mostly unconscious. Keeping these essential characteristics in mind, we can now state our synchronization theory and summarize its components.

In the media context, flow is a discrete, energetically optimized, and gratifying experience resulting from the synchronization of attentional and reward networks under condition of balance between challenge and skill. Our theory of flow is based on the following line of argument: *Flow can be understood as synchronization of a complex, natural system. Synchronization is an organizing and energetically cheap principle in oscillating natural systems. Organization, energetic optimization, and—as a result—balance in a synchronized cognitive system manifests as pleasurable experience*. The following paragraphs summarize our main arguments and offer a set of central hypotheses that can be derived from our theory.

Flow as synchronization of a complex, natural system

The synchronization theory of flow is based on the concept of temporal dynamics in complex, natural systems. In a general sense, systemic temporal dynamics, or rhythms, arise whenever positive and negative forces balance each other in time. We discussed earlier that dynamic systems with an "energy source" become an oscillating system (or an oscillator). Hutcheon and Yarom's (2000) work provided solid evidence that every single neuron in a brain can function as an oscillator and can resonate with other neurons. We also know that groups of neurons can function as oscillators and resonate with other groups of neurons. We described synchronization as a state in which two or more groups of neurons oscillate at the same frequency, and we argued that transitions to a synchronized oscillating system are abrupt (discrete), not continuous, which can be explained with the principle of SOC in natural, dynamic systems. Beggs and Plenz (2003) found empirical evidence for the existence of neuronal network cascades related to behavioral activity. Thus, our first set of arguments posits flow as a synchronization of a complex, natural system of neural networks.

Synchronization as an organizing and energetically cheap principle

Our second set of arguments addresses the *function* of flow as neural synchrony. We discussed the notion that collective neuronal behavior can be established through neural synchronization (cf. Buzsáki, 2006). This assumption goes far back to research from Donald Hebb (1949), who proposed that the brain's ability to generate a coherent thought derives from a spatiotemporal orchestration of its neurons. Hebb simplified his assumption by comparing it to the dynamic interactions among musicians of an orchestra who need to resonate and synchronize in order to produce music. Today, there is ample evidence for Hebb's initial hypothesis (see, e.g., Harris, Csicsvari, Hirase, Dragoi, & Buzsáki, 2003). We also reviewed work by Crick and Koch (1990) and Singer (1999), who identified selective synchronization as critical for the formation and maintenance of cognitive functions. According to their (and others') work, synchronization can be understood as a mechanism for conscious awareness of information and, we think, as key for the understanding of holistic, higher-order experiences that cannot be well explained by their single features. Buzsáki (2006) even goes so far to propose that the self-organization of large numbers of oscillating neurons is a potential source of consciousness (Buzsáki, 2006). He adds that conscious experience is a function of neuronal organization and not size. The cerebellum, for example, is mainly a locally organized structure with comparably few connections to other parts of the brain, and as such can never give rise to conscious experiences (humans without cerebellum, for example, usually experience no impairment of consciousness). "On the other hand, the cerebral cortex, with its self-organized, persistent oscillations and global computational principles, can create qualities and experiences fundamentally different from those provided by input-dependent local processing" (Buzsáki, 2006, p. 372). Furthermore, neural synchronization has been shown to be energetically cheap (cf. Laufs et al., 2003). The audience's rhythmic clapping of hands after a theater play may serve as a simple exemplar. In fact, Neda, Ravasz, Brechet, Vicsek, and Barabási (2000) demonstrated that synchronized clapping increases the transient noise during a cycle, but decreases the overall noise. The explanation for this phenomenon is that people are clapping approximately half as fast during the synchronized compared with the nonsynchronized phases of hand clapping. Thus, through coordination an increased output could be obtained with less effort. This seems to be a recurring principle that evolution has harnessed in many ways.

Organization, energetic optimization, and balance as pleasurable experience

Finally, our third set of arguments refers to the connections between cognitive synchronization and the characteristics of the flow experience. We discussed that in our view, it is central to understand flow experiences as a state of focused attention that is highly pleasurable and rewarding. According to the NPP of communication research, which we mentioned in our introduction, and according to the principle underlying social neuroscience in general (cf. Cacioppo et al., 2007), we assume that all human behavior corresponds to basic neural processes. Thus, when we speak of flow as a synchronization phenomenon we mainly expect cognitive synchronization of attentional neural networks. Given current theorizing we should also see synchronization with the outlined reward (limbic) networks during flow states. Furthermore, understanding flow as a balance phenomenon refers directly to the conditions of a dynamic, oscillating system. We speculate that perhaps the neural equivalent of a specific challenge drives the cognitive system away from one state and the neural equivalent of specific skills that are required to master the challenge pushes it back. We could think of motivational processes and reward as a potential "energy source" that is necessary to fuel an oscillating system. The fact that synchronized oscillating systems are energetically cheap may be a reasonable explanation for *why* flow during task performance is not perceived as taxing and as pleasurable, although one is engaged in a challenging task.

Moreover, the model of nonsynchronization and synchronization as qualitatively different states can serve as an explanation of discrete cognitive states. The notions that (a) transitions into flow experiences are sudden and that (b) no-flow and flow states are discrete states correspond well to the concept of SOC as described above. Similarly, it is important to realize that the emergent phenomena that have been linked with neural synchronization are qualitatively different than the sum of their parts—that is, apprehending an apple is qualitatively different than seeing *separately* the sensations of red, round, etc. The functions of attention and working memory are qualitatively different than the functions of the constituent individual neurons and networks working alone. We propose that flow is no different, in that it is a qualitatively new experience that emerges from the synchronization of specialized neural networks and is perceived as a state of holistic consciousness that is more than its parts.

The three main arguments outlined here suggest a set of testable hypotheses that can be derived from our theory. Empirical research that is based on our synchronization theory of flow should first provide evidence that under flow conditions a synchronization of attentional and reward networks as outlined above can be observed. Thus, the central hypothesis of our cognitive synchronization theory is (H1): *If an individual is exposed to flow inducing stimuli and flow occurs, then specific attentional and reward networks synchronize.* Keller and Bless (2008), for example, have shown a way to experimentally manipulate the balance of skills and challenge in a video game that should induce flow, boredom, or frustration, respectively. An alternative approach to test this central hypothesis will be demonstrated below in our next and final section. Finally, if evidence for H1 can be demonstrated, then further empirical tests should be conducted to demonstrate that *the synchronization of attentional and reward networks occurs in discrete states* (H2), that *network synchronization corresponds to an energetically optimized state* (H3), and that *network synchronization manifests as an enjoyable experience* (H4).

Preliminary empirical support

Although this article has a theoretical focus, there is already limited empirical evidence for our proposition. In addition to previous work that has studied cognitive binding and network synchronization (see the discussion above), (Weber, Alicea, and Mathiak, 2009) recently conducted a fMRI study in order to better understand the dynamics of attentional networks in complex, mediated interactive environments. In this study a first-person shooter video game was used as the experimental stimulus. Although 13 male participants played the video game for about 1 hour during fMRI, a potentially distracting mechanism in the form of a laser light pointer was introduced at random intervals. Participants were instructed to respond to this secondary perturbator task by pushing a button with their left hand. Reaction times to the secondary task and the frequency of laser point presentations were used to define a distraction measure (D_Δ) as follows:

$$D_\Delta = \frac{1}{I_p \times I_r} \tag{1}$$

D_Δ calculates the inverse of the mean time interval between laser light presentations (I_p) multiplied by the mean response time to each presentation of the laser light (I_r) within a time interval Δ. The more laser light presentations ($I_p \rightarrow 0$) and the faster participants' response to those laser light presentations ($I_r \rightarrow 0$) the higher the distraction from the primary task and the less likely a state of focused attention to the primary task (playing the video game).

Lang and Basil (1998) and Lang, Bradley, Park, Shin, and Chung (2006) show that secondary task response times are a reliable and valid measure of available attentional resources. Moreover, Kantor and Weber's (2009) experiment demonstrates that available attentional resources provide a valid indicator of a flow experience. Weber, Alicea, and Mathiak (2009) have shown that the definition of network connectivity (C) as the average interregional correlation (r_c) in time interval Δ between (fMRI) BOLD signal values in distributed neural networks[2] can be considered as a measurement of network synchronicity. Hence, although the goal of Weber, Alicea, and Mathiak's (2009) study was not an investigation of flow experiences during game play but rather an exploration of attentional networks, the study revealed several interesting patterns pertaining to our present assertion. It could be shown (see Figure 1) that with decreasing distraction (i.e., increasing attention to the primary task/flow) functional connectivity (synchronicity) among attentional networks slightly increased as the distraction measurement neared a threshold value T (up to $r_c \approx 0.1$), but clearly increased as the distraction measurement exceeded threshold T (up to $r_c \approx 0.5$).

Most interestingly for our consideration is that the increase of functional connectivity included parts of the reward networks discussed above. At some critical value of distraction, synchronous activations of attentional and inner limbic cortical regions could be observed. We see this as initial evidence that our synchronization theory of flow has scientific merit.

Limitations and future research

It is apparent from the underdeveloped nature of the preceding section that although we can see some evidence consistent with our cognitive-synchronization theory, testing of the theory is in its infancy, and excessive confidence is unwarranted at this early stage. As any scientific theory is speculative and heuristic, our proposition is speculative at this point and needs further empirical support. Nevertheless, the

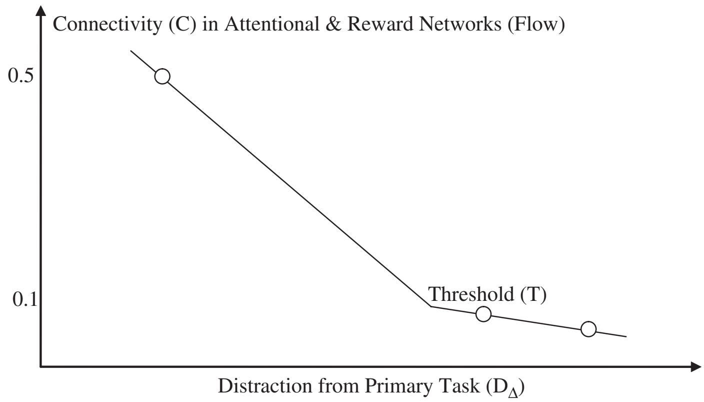

Figure 1 Functional connectivity in attentional and reward networks as a function of distraction from the primary task "playing a first person shooter video game."

potential importance of observing evidence consistent with our a priori prediction of this complex neurological pattern should not be overlooked.

Attempts to provide additional evidence should begin with simple replication that provides new subjects performing different tasks (e.g., playing different games). More convincing evidence could be provided by research using experimental controls designed specifically to manipulate the onset of flow during play. For example, varying features of the video-game environment to create a balance or imbalance between player skill and challenge should produce conditions conducive to peak and nadir experiences of flow. Observations showing predicted patterns in the hypothesized synchronization of attentional and reward networks would greatly add to needed confidence. Recent research examining flow and intrinsic motivation in video games shows evidence of successful attempts to manipulate the balance between challenge and skill by programming three distinct playing modes of the classic video-game Tetris so that the speed with which objects in the game keep falling is varied to either match the player's evolving skill level throughout the game (the balanced condition), or to go either slower (the boredom condition) or to go faster (the frustration condition) than the player's skill level (Keller & Bless, 2008; see also Kantor and Weber, 2009).

Furthermore, attempts to replicate should also focus on efforts to repeat our findings with alternative indicators of flow. For example, investigators attempting to study flow in video-game environments have provided initial evidence relating physiological measures to the experience of flow. Mandryk et al. (2006) found that subjective self-report of fun and frustration was correlated with elevated levels of galvanic skin responses (GSRs) during video-game play. These authors also recommend observation via electromyography (EMG) along the jaw to measure forms of corrugator zygomaticus major activity (smiling) and supercilii activity (frowning) that have been shown to increase and decrease, respectively, with positive and negative emotions (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000; Partala & Surakka, 2004).

It is important to note that even if replication produces the level of confidence necessary to use our cognitive-synchronization theory, the unavailability of fMRI (and even EEG) technology to most researchers would limit the convenient use of our proposition. In this regard, the next step in our research is to identify reliable correlates of the hypothesized synchronization of attentional and limbic networks that can be more easily observed and used to indicate the existence of flow states.

We started in this article with an exploratory, operational, and generalizable theory explicating flow as the synchronization of attentional and reward (limbic) neural networks and provided explanations of *why* this cognitive synchronization occurs. At times it seems that the biggest threat to any theory in the social sciences is describing it clearly enough to be refuted. We, however, see the clear potential for falsification as the strength of our proposition. Based on the promising signs in a preliminary investigation, we hope that researchers will be encouraged to join us in efforts to replicate these initial findings with strong research designs using different experimental settings. In doing so, we may be able to unravel one of the more complex phenomena within both the area of media enjoyment and the cognitive sciences—or find that we should go in another direction.

Notes

1 The domain of flow is limited to the types of media and communicative circumstances that require some level of skill, in order for the antecedent condition of a skill/ability balance to occur. Theoretically, this means that the types of media that are conducive to flow are more conscious "mindful" media that involve active attention and effort (thus, skill) on the part of the media user. One could argue that the flow state itself results in a *kind* of "mindlessness" in that, by our definition, during flow attentional resources are so consumed by the media task that the user is "mindless" to everything except the task at hand, with none left over for even conscious attention to oneself and such "basic" perceptions as the passage of time. However, the "mindful" nature of active attention and effort distinguishes flow as a "mindful" experience.

2 Simplified, this means that connectivity among neural networks is measured with the average correlation between network activity in time interval Δ.

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