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# The Psychological and Neurological Bases of Leader Self-Complexity and Effects on Adaptive Decision-Making

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Complex contexts and environments require leaders to be highly adaptive and to adjust their behavioral responses to meet diverse role demands. Such adaptability may be contingent upon leaders having requisite complexity to facilitate effectiveness across a range of roles. However, there exists little empirical understanding of the etiology or basis of leader complexity. To this end, we conceptualized a model of leader self-complexity that is inclusive of both the mind (the complexity of leaders' self-concepts) and the brain (the neuroscientific basis for complex leadership). We derived psychometric and neurologically based measures, the latter based on quantitative electroencephalogram (qEEG) profiles of leader self-complexity, and tested their separate effects on the adaptive decision-making of 103 military leaders. Results demonstrated that both measures accounted for unique variance in external ratings of adaptive decision-making. We discuss how these findings provide a deeper understanding of the latent and dynamic mechanisms that underpin leaders' self-complexity and their adaptability.

*Keywords:* leader complexity, self-complexity, neuroscience, adaptability

Leaders often operate in complex situations in which they grapple with dynamic social systems or networks and make decisions pertaining to erratic and changing internal and external environments. Inevitably, these changing situations create unpredictability and tension that leaders are required to negotiate to achieve effectiveness. In order to respond to such demands, scholars have suggested that more effective leaders possess a requisite level of complexity that allows them to accurately perceive and assess these complex and changing dynamics, and in turn, adapt their decision-making and behaviors to enact effective responses (e.g., Denison, Hooijberg, & Quinn, 1995; Zaccaro, Gilbert, Thor, & Mumford, 1991).

We seek to advance an understanding of what constitutes leader complexity because it may be a key enabler of *adaptation* (Hooijberg, Hunt, & Dodge, 1997). Based on his review of the adaptation literature, Chan (2000, p. 4) stated that adaptation "refers to the process by which an individual achieves some degree of fit between his or her behaviors and the new work demands created by the novel and often ill-defined problems resulting from changing and uncertain work situations." Note that this definition does not specify the attributes that make an individual more or less capable of adaptation, that is, an individual's level of *adaptability*. While scholars generally agree on definitions of adaptation as entailing the process of establishing behavioral fit with changing and novel situations, according to Chan (2000), there is much less consensus as to what makes an individual more or less adaptable. To advance an understanding of adaptability as applied to leadership, we present and test a theory of leader complexity as a predictor of leader adaptation to change.

We define *leader adaptability* as the capacity of leaders to adjust their thoughts and behaviors to enact appropriate responses to novel, ill-defined, changing, and evolving decision-making situations (Chan, 2000; Denison et al., 1995; Paulhus & Martin, 1988; Pulakos, Arad, Donovan, & Plamondon, 2000). Greater levels of complexity promote leaders' ability to both differentiate

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the various sources of inputs and stimuli in the environment *and* to integrate those inputs with existing cognitive and affective structures to enable adaptive responses (R. G. Lord, Hannah, & Jennings, 2011; Zaccaro, Foti, & Kenny, 1991). Differentiation refers to the capacity to determine the various unique dimensions underlying a particular perceptual domain. Yet differentiation promotes integration, the capacity to perceive the relationships or correlations among these dimensions (e.g., the patterns, linkages, or themes existing between concepts) and to synthesize them to achieve a deeper level of situational awareness and understanding in dynamic and changing contexts (Streufert & Nogami, 1989; Weick & Bougon, 1986).

Based on a complexity approach, Day and Lance (2004) argued that leader development is similar to the growth of an organism as it matures and achieves greater complexity over time, thereby leading to its successful adaptation to a changing environment. Accordingly, an examination of psychological and neurological markers of leader complexity is an important first step in advancing leader development along these lines. While a limited set of theories of leader complexity have been offered (e.g., Hooijberg et al., 1997; R. G. Lord et al., 2011), they have not been operationalized, leaving leader complexity an underdeveloped and untested concept.

In the current investigation, we specifically examine leader self-complexity (LSC), which is based on the self's central role in managing the interface between a leader's internal processes (e.g., goal systems, self-regulation, and identity) and his or her interactions with the social environment (Hannah, Woolfolk, & Lord, 2009). The self provides the structure through which leaders organize their various social roles and the knowledge, skills, abilities, and self-regulatory systems associated with those roles (R. G. Lord & Hall, 2005; R. G. Lord et al., 2011). We propose that greater levels of complexity enhance a leader's ability to comprehend and react adaptively to dynamic decision-making situations (Hannah, Lord, & Pearce, 2011).

To formulate an etiology of LSC, we include both psychometric and neurological processes, of which the latter are considered to be the foundations of mental activity and behavior (Bear, Connors, & Paradiso, 2006). We employ a multimethod approach (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003) to form and test hypotheses specifying that there are both psychological and neurological markers of LSC. Specifically, we incorporate techniques from clinical and social psychology (Linville, 1987; Woolfolk, Gara, Allen, & Beaver, 2004) to create an index of psychological LSC. Further, we use a neuroimaging technique (quantitative electroencephalography, or qEEG) to derive a neurologically based index of intrinsic brain activity in regions and frequencies that support self-relevant knowledge and information processing, self-regulatory functions, decision-making, and behavior (for reviews, see Banfield, Wyland, Macrae, Munte, & Heatherton, 2004; Lieberman & Eienberger, 2004; Lieberman & Pfeifer, 2005). We hypothesize that neurological LSC, as a derivative of relatively stable brain functionality, enhances leaders' adaptability through providing the capacity to process and effectively respond to dynamic, changing and unpredictable situations (Daffner et al., 2003), reduce ambiguity and make meaningful decisions (Damasio, 1996), and manage other aspects of social conduct and emotional processing (Tranel, Bechara, & Denburg, 2002). Finally, we assess the influence of psychological and neurological LSC on leader adaptability, operationalized as adaptive decision-making in dynamic leadership scenarios. In short, this study seeks to serve as a first step in achieving a greater understanding of what constitutes LSC and its outcomes.

## The Psychological Bases for Leader Self-Complexity and Adaptive Decision-Making

### The Nature of Psychological Leader Self-Complexity

In general, cognitive complexity provides an individual the capacity to effectively differentiate, as well as integrate, perceptual and abstract information in those domains for which he or she is complex (Streufert & Nagami, 1989; Streufert & Swezey, 1986). By *domain*, we refer not to narrow tasks or groups of tasks, but as we describe further below, expanded role sets. Based on his or her training, education and experience, a leader may, for example, become complex in the role sets associated with the general domain of military leadership and be relatively less complex in the domain of business leadership. Hannah, Lord, and colleagues (Hannah et al., 2009, 2011; R. G. Lord et al., 2011) extended the more general prior theoretical work on leader complexity (e.g., Denison et al., 1995; Hooijberg et al., 1997) by highlighting the central role of LSC in driving leader effectiveness and performance.

LSC builds upon clinical and social psychological research areas, including self-complexity and identity theories, information processing and self-regulation theories, and role theory. First, self-complexity theory assesses the self-concept as a highly differentiated structure that uniquely drives information processing and self-regulation (Linville, 1987; Linville & Carlston, 1994; Woolfolk et al., 2004). This is because the self-relevant knowledge that composes self-complexity is unique compared to other forms of cognitive complexity in its greater richness and salience (Kihlstrom & Klein, 1994) and thus imposes significant effects on information processing and self-regulation (Stahlberg, Peterson, & Dauenheimer, 1999; Verplanken & Holland, 2002). Further, the self has been found to have unique neurological underpinnings (e.g., Kelley et al., 2002; Platek, Keenan, Gallup, & Mohamed, 2004; Platek, Wathne, Tierney, & Thomson, 2008), as we hypothesize in the next section.

LSC reflects the level of richness and complexity with which leaders psychologically structure their self-concepts (Hannah et al., 2009). Specifically, the self-concept can be defined as more or less complex based on the breadth of roles (e.g., team leader, mentor, spokesperson) with which leaders characterize themselves, as well as the breadth of self-aspects contained in each role (e.g., skills, traits, attributes, and self-regulatory structures). LSC is thought to be critical for leader effectiveness because the self serves as the interface between the surface-level observable traits and behaviors that leaders exhibit and the deeper metacognitive structures that enable leaders to construct a sophisticated understanding of situations and that drive a broad repertoire of thoughts and behaviors (R. G. Lord & Hall, 2005; R. G. Lord et al., 2011). The self-concept is thus central to leader self-regulation and performance. As noted by Kihlstrom and Klein (1994, p. 194), the self is "the point at which cognitive, personality, and social psychology meet."

LSC is also based on role theory. A *role* refers to a cluster of behaviors, skills, attitudes and other factors that are thought to belong together and enable functioning in a given social context (Turner, 2002). Individuals occupying a particular position, e.g., military commander, are likely to develop an expanding *role set* over time, whereby new subroles arise through experience as a way to successfully deal with the demands of the various situations that they face in that role (Karaevli & Hall, 2006). Over time, these competencies become integrated and organized into increasingly multifaceted sets of knowledge structures that are integrated with the leader's identity and with goals, self-regulatory plans, and other self-aspects that expand LSC (R. G. Lord et al., 2011).

For example, research with U.S. Army cadets and junior officers (Hannah, Jennings, & Ben-Yoav Nobel, 2010) suggests that officers may begin their careers with a fairly ill-defined self-concept as a military leader, and through training, education, and the facing of various role demands over time, they are likely to create more refined subroles such as tactical warfighter, tactical civil affairs manager, diplomat and negotiator, intelligence manager, and troop and unit leader. Further, each subrole is populated with a necessary set of self-aspects that expand over time to meet the role requirements of each subrole. LSC thus represents an idiosyncratic, hierarchical cognitive structure formed through social learning (Bandura, 1977). This is consistent with Day and Lance's (2004) view of leader development as being similar to an adapting organism, gaining complexity over time in response to the environment, with increasingly expanding LSC to meet role demands.

LSC is therefore built in part as leaders' self-concepts become more differentiated over time; yet it is important to recognize that differentiation and integration are not orthogonal, but represent opposite sides of the LSC "coin." That is, differentiation allows the leader "to see color, shapes, and shades of gray on the canvas of social context," whereas integration allows the leader "to focus on whole objects in order to form a coherent, meaningful picture from among the colors, shapes and shades" (Hooijberg et al., 1997, p. 385). This is because the rich perceptual lens provided by differentiation enhances leaders' capacity to find commonalities and themes across differentiated factors and better perceive both the surface structures and deep structures of leadership problems (Smith, Ford, & Kozlowski, 1997). This, in turn, allows the leader to understand how their knowledge, skills, abilities and other attributes are related to and can be applied to challenges (Karaevli & Hall, 2006; R. G. Lord et al., 2011).

Finally, it is important to distinguish self-complexity theory (Linville, 1987), upon which LSC is based, from *social identity complexity*, which is based on social identity and social categorization theories. In their seminal article introducing the social identity complexity construct, Roccas and Brewer (2002, p. 94) stated that these two constructs "differ in the type of knowledge at their focus: self-complexity refers to the structure of the perception of personal attributes, whereas social identity theory refers to the perception of in-groups." By *in-groups*, they refer to "large, symbolic groups [with] collective identities that are depersonalized" (Roccas & Brewer, p. 89), such as race, ethnic, religious, socioeconomic, and other social categorizations. They propose that individuals can have more or less complex representations as to their membership in such various social categories.

## Psychological Leader Self-Complexity and Adaptive Decision-Making

Pulakos and colleagues (Pulakos et al., 2000, 2002) proposed that *adaptability,* operationalized as *adaptive decision-making* here, can be described through behavioral dimensions that include solving problems creatively, dealing with changing, uncertain, or unpredictable work situations, and handling emergencies or crisis situations. Adaptive decision-making consists of high levels of situational awareness, coupled with the ability to use that awareness to guide the formation of decisions that positively and actively address the situation at hand in an adaptive manner. Endsley (1995a, p. 65) defined situational awareness as "a person's perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future." An application of the three stages of situational awareness from the work of Endsley (1995a, 1995b) to adaptation would specify that the leader be capable of (a) perceiving both that changes are occurring in the environment and key information relevant to those changes, (b) interpreting that information and integrating it with the leader's goals to comprehend the implications that those changes have for the leader's current actions and strategies, and (c) making predictions as to future events and system states that are likely to occur in the changed context. From this heightened state of awareness, leaders then employ existing knowledge to choose new actions and strategies that will reestablish fit and effectiveness in the changed context.

Such adaptive decision-making is supported by underlying knowledge, skills, abilities, and other characteristics (KSAOs) that vary in their necessity across different situations. We argue that LSC provides the superordinate structure for these KSAOs and other self-aspects (e.g., self-regulatory and metacognitive structures) ordered across roles and subroles. LSC is thus an individual difference underpinning leader adaptability.

To link LSC to leader adaptive decision-making, we start with the concept of *leader requisite complexity* (Hannah, Eggers, & Jennings, 2008), which derives from Ashby's (1956) *law of requisite variety*. It holds that to effectively regulate a system, the complexity in the leader must be sufficient, i.e., is requisite relative to the level of complexity in the system being regulated. Hannah et al. (2009) proposed that this occurs because a more complex structuring (i.e., differentiation and integration) of the self will provide leaders with a more expansive repertoire of identities and associated skills and other self-aspects, which they can then access and employ to enhance their adaptability across changing situations.

As LSC includes not just knowledge and skills but also associated self-regulatory and metacognitive structures, LSC will enable individuals to recognize novelty or change, select potential responses, monitor and evaluate progress, and create different responses to the task if necessary—all of which are critical aspects of adaptability (Bell & Kozlowski, 2002, 2008). Further, we note that LSC facilitates integration, the recognition of the deep structural features of tasks and problems, which Chan (2000) suggested are critical components of adaptability. The structural features of a problem are functionally related to outcomes or goal attainment (Gick & Holyoak, 1987), and an understanding of these deep structures allows the leader to identify situations in which existing behaviors may or may not apply. When they do not apply, a more complex leader can select and transfer other appropriate behaviors from his or her repertoire or create new ones (Holyoak, 1991; Kimball & Holyoak, 2000). A less complex leader may either not comprehend the deep structure of a given problem or have a lesser repertoire of KSAOs to apply to the problem, leading to an inappropriate or ineffective response. In a military situation, for example, a less complex leader may respond with lethal force, while a more complex leader may understand that negotiation is more appropriate, as well as be able to access the related attributes, skills, and self-regulatory structures that facilitate the needed negotiation behaviors. Indeed, Paulhus and Martin (1988) noted that having a wide repertoire of knowledge, behaviors, and strategies is common across various conceptualizations of adaptability (cf. Chan, 2000).

The learning that underlies such leader adaptability includes both task learning and personal learning, of which the latter enhances one's understanding of him or herself, one's identity, capabilities, and other attributes related to task accomplishment (Karaevli & Hall, 2006). The self thus serves as the interface between the behaviors that leaders exhibit and the deeper structures that drive adaptive performance (R. G. Lord & Hall, 2005). R. G. Lord et al. (2011) provided a model to explain the emergence of complexity within leaders and resultant adaptation. They propose that as leaders face task demands, identity structures are primed that "set off" the initiation of self-regulatory functions across five hierarchical levels: (a) perception, (b) consciousness, (c) goal emergence, (d) affect systems, and (e) at the highest level of the hierarchy, these lower structures aggregate to activate a tailored *working self-concept* (WSC). The WSC "grounds self-regulation in social constraints, active roles, value systems, and past experience; creates a storehouse of autobiographical experiences and draws upon these experiences to guide actions; activates relevant emotions . . . [and thus] . . . both exploration of the current environment and exploitation of past learning are facilitated" (R. G. Lord et al., 2011, p. 8). Critical to adaptive decision-making, the self constrains information processing, since leaders' level of complexity binds their ability to employ a tailored WSC and access expertise (Hannah et al., 2009).

Many decision-making challenges that leaders face are naturally adaptive, rather than veridical. Veridical decision-making involves the uncovering of the correct response according to the parameters of the situation and regardless of the decision-maker's goals. In contrast, adaptive decision-making is leader-centered and is guided by the leader's goals and priorities (Goldberg & Podell, 2000). Thus, leaders who can best access an expanded set of relevant knowledge and skills and self-regulatory structures to understand problems and form tailored working self-concepts should be better positioned to involve the self in the deliberations and guide the process through their goals and priorities.

In sum, LSC facilitates adaptive decision-making by providing a more differentiated set of role structures and associated attributes. This set allows access to an expanded mix of relevant knowledge and skills and self-regulatory structures to achieve enhanced integration and thus a deeper understanding of problems, forming a tailored WSC, which increases adaptability (R. G. Lord et al., 2011). This leads to our first hypothesis:

> *Hypothesis 1:* Leaders with higher levels of psychological LSC will demonstrate higher levels of adaptive decision-making.

We propose that the psychological component of LSC (the "mind") provides only a limited explanation of overall LSC. In proposing future directions for their theory of LSC, R. G. Lord et al. (2011) recommended that neuroscience could improve our understanding of LSC by illuminating neurological capacity for LSC (the "brain"). By defining a broader construct that identifies the neural mechanisms that characterize LSC, we could potentially guide leadership development and the measurement of leaders' growth in complexity over time. That is, if areas of the brain, as well as neurological variables emanating from the study of those areas, can be associated with LSC, then we may gain insights into developing and employing those brain capacities in leaders.

## The Neurological Basis for Leader Self-Complexity and Adaptive Decision-Making

### The Nature of Neurological Self-Complexity of Leaders

Electrical activity of neural cell assemblies occurs at a variety of frequency ranges and spatial distributions across the brain (Creutzfeldt, 1995; Elbert, 1993; Mitzdorf, 1991; Niedermeyer & da Silva, 2005). Cacioppo et al. (2003) suggested that most complex behavioral concepts, such as LSC, do not map onto a single discrete spatial location in the brain but, instead, are likely to reflect multiple parts of the brain acting across a distributed, but interconnected network of neuronal regions (Cacioppo, Berntson, & Nusbaum, 2008; Hagmann et al., 2008; Nolte & Sundsten, 2002). We propose that there is an inherent brain capacity or structure relevant to neurologically based LSC, which is malleable and developed through leaders' experiences but is relatively stable over time, providing a biologically based capacity for LSC.

This intrinsic capacity can be examined through brain activity when an individual is in a resting (i.e., not processing discernible stimuli), albeit in an awake state (Waldman, Balthazard, & Peterson, 2011). A growing body of neuroscience research suggests that the neural pattern found when the brain is at rest reflects its core functional connectivity and the inherent and stable brain functioning or capacity of an individual (Raichle & Snyder, 2007). Indeed, Cacioppo et al. (2003) suggested that the brain in a resting state is not passive but involves its own set of potentially meaningful neural operations shown to include memory consolidation and learning (Tambini, Ketz, & Davachi, 2010). Fox and Raichle (2007) reported that at rest, brain activity patterns correspond to patterns during task engagement. Waldman et al. (2011) further proposed that the brain structure when at rest could reflect meaningful leadership capacities, such as LSC.

To assess this intrinsic network as a basis for LSC we examined three fundamental electrophysiological concepts that characterize brain functioning: (a) characteristics of the electrical signal in terms of frequency and amplitude, (b) spatial location of the sources of brain electrical activity, and (c) pattern of connectivity across the brain (neural network dynamics).

**Amplitude and frequency.** In general, the more relaxed or inattentive a person is, the greater the amplitude and the lower the frequency of the waves in the brain. In contrast, the lower the amplitude and the greater the frequency, the more likely it is that the person is in an excited, working, or attentive state. The amplitude and frequency of brain waves can be assessed with regard to five bandwidths ranging from deep low arousal (e.g., inattentive, sleeping) to high arousal (extreme alertness). These five bandwidths are from lowest to highest arousal levels: *delta*, *theta, alpha, beta*, and *gamma* rhythms, respectively.

One of the most prominent bandwidths is the alpha rhythm, an oscillation in the range of 8–13 Hz with an average peak of 10–11 Hz in healthy adults. Alpha rhythms are associated with relaxation, contemplation, internal focus (e.g., the self), and mental performance, both in healthy individuals and in individuals with neurological conditions (for reviews, see Angelakis, Lubar, Stathopoulou, & Kounios, 2004; Klimesch, 1997). Indeed, most of the EEG studies examining task engagement, cognitive functions, and brain complexity report activity in the alpha band, showing that alpha activity is inversely related to mental effort (e.g., Burgess & Gruzelier, 1997; Butler & Glass, 1976; Donchin, Kutas, & McCarthy, 1977; Glass, 1964; Gutiérrez & Corsi-Cabrera, 1988; Nunez, 1995; Pfurtscheller, Stancak, & Neuper, 1996). Further, recent research has shown that episodic memory, another cognitive process related to brain complexity, exhibits patterns of activity in the alpha frequency range (e.g., Hanslmayr, Spitzer, & Bäuml, 2009; Zion-Golumbic, Kutas, & Bentin, 2010). Accordingly, as we explain in further detail in the methods section, we posit that neural synchronies within the alpha range, particularly since they are captured with the brain in its intrinsic state (i.e., a condition when alpha waves are naturally prevalent), are appropriate to examine as potential markers of neurological LSC.

**Spatial location.** Beyond defining the appropriate frequency to emphasize in our analyses, identifying parts of the brain that are theoretically associated with LSC is also an important consideration. LSC is derived from leaders' abilities to execute increasingly complex cognitive processes that provide the requisite complexity to effectively comprehend, adjust to, and engage with the environment (Hannah et al., 2009; R. G. Lord et al., 2011). By understanding neurologically the locations where cognitive functions associated with LSC occur (e.g., perception, consciousness, goal emergence, affect, and the self—including self-knowledge, self-regulation, and so forth), we seek to define a biological marker of LSC.

Several studies have used a neurological approach to identify, at least in part, the frontal lobes as a key location for the mental representation of knowledge about the self and self—related judgments (e.g., Craik et al., 1999; Devue et al., 2007; Esslen, Metzler, Pascual-Marqui, & Jäncke, 2008; Klein et al., 2009; Klein, Robertson, & Delton, 2010; Mu & Han, 2010; Platek et al., 2004, 2008; Shi, Zhou, Liu, Zhang, & Han, 2011; Symons & Johnson, 1997; for reviews see Lieberman & Eienberger, 2004, and Lieberman & Pfeifer, 2005). An overarching proposition in these studies is that the self can be conceptualized as a complex knowledge structure characterized by *at least* two neurally and functionally independent, component systems linked to the frontal lobes: (a) episodic memory (i.e., the memory of time, places, associated emotions, and other contextual knowledge that can be explicitly stated) and (b) semantic memory (i.e., memory of meanings and understandings, and other concept-based knowledge unrelated to specific experiences; e.g., Klein & Loftus, 1993; Klein, Loftus, & Kihlstrom, 1996; C. G. Lord, 1993; Tulving, 1993).

Episodic memory contributes to self-knowledge by enabling the leader to recall specific events and experiences that occurred in his or her past. It provides a personal narrative and a sense of self in relation to these events through time. By contrast, semantic memory is made up of generic, context-free knowledge, enabling the leader to know facts and generalizations about his or her traits, dispositions, capabilities, and other attributes without having to consciously recollect specific episodes upon which that knowledge is based.

Executive function is yet another neural process based in the frontal lobes that is central to the neurobiology of LSC. It helps connect past experiences with present action and synchronizes the activities of other cognitive processes to accomplish a task. With respect to LSC, executive function is an umbrella term for compatible cognitive processes, such as planning, strategizing, paying attention to and remembering details, problem solving, managing time and space, and initiation and monitoring of actions (Ben Shalom, 2000; Davidson & Irwin, 1999; Grady, 1999; Kelley et al., 2002; Vogeley, Kurthen, Falkai, & Maier, 1999), to include judgments about the self (Lieberman & Eienberger, 2004; Lieberman & Pfeifer, 2005). Thus, the capacity of a leader to richly store and effectively employ memory systems in conjunction with executive functioning may represent a neurological basis for LSC.

Substantial research has defined various neural coordinates for these memory and executive functioning processes that we suggest facilitate LSC. The frontal cortex, especially in prefrontal areas, is understood to be the seat of executive functioning (Chow & Cummings, 1999; Kaufer & Lewis, 1999) and the executive control of behavior (Goldstein, 1944; Jastrowitz, 1888; Luria, 1980). The frontal cortex is the top of a hierarchy of neural structures that integrate external information and internal states for the representation, temporal organization, and the execution of complex mental and behavioral responses to environmental challenges, such as those involved in leadership (Case, 1992; Fuster, 1999). The frontal cortex is connected with nearly all other cortices, subcortical structures, and brain stem nuclei, allowing it access to and control of a breadth of cognitive resources (Fuster, 1993, 1999). A substructure known as the ventromedial prefrontal cortex has also been shown to work in cooperation with limbic areas as a regulator of emotion for efficient mental functioning in the pragmatics of social life, including the self-regulation of agency and goal-directed activity, social self-awareness, decision-making, and moral behavior (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Damasio et al., 2000). Further, Shi et al. (2011) and Esslen et al. (2008) localized first-person perspectives and self-referential content in the medial frontal lobes and anterior cingulate gyrus (i.e., medial surface of the frontal lobes).

Additionally, neuroimaging studies of episodic memory (for instance, hemispheric encoding and retrieval asymmetry) have indicated frontal lobe involvement (strongly interconnected with limbic areas) with the left frontal hemisphere more involved than the right in encoding, and the right more than the left in retrieval (e.g., Habib, Nyberg, & Tulving, 2003). Evidence has also linked the left prefrontal cortex, among other brain regions, to semantic memory processes (Martin, 2001). Both episodic memory and semantic memory require a similar encoding process, and while semantic memories may originate in a personal context, a gradual transition from episodic to semantic memory can take place, in which episodic memory reduces its sensitivity and association to particular events so that the information can be generalized. Specific knowledge of the self can thus become more generalized over time, facilitating its transfer to new situations. It is not surprising then that they both rely on processes that reside in the frontal lobes. Therefore, we conclude that many of the neurological capacities required for LSC reside in the frontal lobes of the brain.

**Connectivity.** The third fundamental, electrophysiological concept that we suggest provides the capacity for neurological LSC entails the pattern of connectivity between sources of electricity across the brain. The study of connectivity can be used to address the issue of functional communication in the cortex. Connectivity refers to the extent that parts of the brain are working together in a synchronous manner.

The importance of brain connectivity or synchronization in a study of LSC is that it can reveal aspects of the level of complexity that is present in the intrinsic network in the brains of leaders. For example, connectivity reflects the strength of connections between groups of neurons in different brain locations. The brain is composed of local networks (group of neurons within 1 cm of each other), as well as much longer networks (groups of neurons separated by more than 3 cm), that link local networks of neurons to others (akin to a "hub and spoke" system used by major airlines). These longer networks are formed over time as individuals develop and create larger brain-scale systems that allow them to recruit and process diverse knowledge and other resources from various other local networks as needed (Breakspear, 2004; Thatcher, North, & Biver, 2005, 2012; Bassett & Bullmore, 2006). Increased distant differentiation, operationalized in terms of lower connectivity or desynchronization, gives rise to increased complexity during human brain development (Breakspear & Stam, 2005; Thatcher, 1998; Thatcher, Krause, & Hrybyk, 1986).

A leader with a more differentiated complex brain (represented by lower connectivity or desynchronization) might have a richer "hub and spoke" neurophysiological network, thereby providing access to more distributed brain resources. Yet they would also utilize this network more efficiently and in a more differentiated manner. Efficiency of information processing is related to the time delays in activity between synchronous groups of neurons, as well as the complexity of neural networks in high-speed, long distance neuron connections that coordinate the functional modules of the brain (Hagmann et al., 2008; Thatcher et al., 2005, 2012). This more differentiated brain is able to recruit resources from diverse neural networks, form them into momentary processing structures to address leadership task demands, and then efficiently release those structures and recruit others as needed. Such processing occurs in milliseconds, creating a differentiated processing "landscape" across the brain, as reflected in low levels of connectivity. A less complex leader's brain would show higher levels of connectivity, whereby greater expanses of the brain are indiscriminately locked together in the same amplitude and frequency, leaving fewer resources for other leadership processing tasks. As a simplification or analogy, this is akin to a single-core versus a multicore computer processor chip that allocates differentiated resources to task demands. As described earlier, this greater neurological differentiation then facilitates cognitive integration, or the ability to determine surface and structural components of task challenges and develop more holistic perceptions.

In sum, we propose a neurological marker of LSC by combining the three fundamental electrophysiological concepts described above. That is, the prior research that we reviewed suggests that an appropriate neurological marker of LSC can be developed by assessing the level of connectivity in the alpha range, situated in the intrinsic neural network of the frontal lobes of the brain, where self-relevant memory and executive function processing are centered.

## Neurological Leader Self-Complexity and Adaptive Decision-Making

Initial forays to understand potential connections between neurological structures and decision-making can be seen in systematic examinations of medical patients with well-defined brain lesions (for reviews, see Bechara, 2004; Damasio, 1996). This body of work not only identified brain regions essential for adaptive decision-making but also provided conceptual models of critical aspects of decision-making, for example, the somatic marker theory which indicates the intensity and valence of a stimuli experienced by the decision-maker (Damasio, 1996). A variety of regions are likely to be involved in different functions relevant to adaptive decision-making, such as parietal lobes in computation (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999) and in assessment of probability (Ernst et al., 2004; Shadlen & Newsome, 2001), anterior cingulate cortex associated with processes of uncertainty (Critchley, Mathia, & Dolan, 2001; Elliott, Rees, & Dolan, 1999) and the integration of successes and errors over time (Carter et al., 1998). However, regions of the prefrontal cortex, not surprisingly, have been found to be especially critical for adaptive decision-making (Christakou, Brammer, Giampietro, & Rubia, 2009).

We have described leaders with higher brain complexity in the frontal lobes (i.e., lower connectivity in the alpha frequency range) as having richer semantic and episodic memory, as well as enhanced executive functioning. Such leaders will be able to access a more diverse set of cognitive resources across long range neural network connections, form them into momentary processing structures, and then efficiently release those structures and recruit others as needed to enhance the perception and processing of leadership tasks. Adaptive experts practice such flexible switching among alternate possible strategies, versus conducting some form of sequential search strategy (Kimball & Holyoak, 2000). Leaders who can only recruit from a limited knowledge base, in contrast, engage in less information search and are more bounded in their reasoning (Cyert & March, 1963). Enhanced executive functioning, such as metacognitive ability, also facilitates the ability to transfer expertise gained from prior experiences to new experiences and has been shown to enhance adaptability (Smith et al., 1997). This is because lower connectivity in the alpha range provides access to a richer set of expert knowledge structures and effective executive functioning, which, in turn, allows leaders to differentiate and thus perceive the complexity of a problem. It also allows the leader to integrate those perceptions to determine the underlying structural components of new or novel tasks. They can then assess the applicability of, or modify, expertise gained from experience with prior tasks to a new task that has a similar structural base, enhancing their adaptability across situations.

The process described above represents the highest form of transfer of expertise as described by Smith et al. (1997, p. 109), which occurs through "adapting different methods from those learned in training and using existing knowledge to generate new approaches and strategies," also referred to as *adaptive expertise* by Kimball and Holyoak (2000). Importantly, highly complex individuals may exhibit what has been called metacomplexity (Streufert & Nogami, 1989), which represents the ability to not only assess the complex factors present in a situation, but then determine when a more or less simple or complex processing mode and solution is needed. They may in essence be able to make sense out of chaos and realize that the deep structural features of problem indeed allow a quite simple response. We believe this capacity to be reflective of neural patterns showing lower connectivity in the alpha range in the frontal lobes.

We also know that through the ability to recruit and process richer cognitive resources, leaders can better link problem definitions with solutions (Chi & Glaser, 1985). Finally, leader adaptability has been proposed to require the integration of both task- and self-relevant information (Karaevli & Hall, 2006), and thus the self-regulatory capacities of the frontal lobes coupled with access to rich self-relevant knowledge (e.g., Banfield et al., 2004; Klein et al., 1996, 2010) would be critical in sponsoring adaptability.

In sum, we have established the possibility of neurologically based LSC as a biological marker and relatively enduring individual characteristic based largely in the frontal lobes. We also defined lower alpha connectivity in the frontal lobe as an appropriate measure for LSC, reflecting greater brain complexity, which we propose will produce more adaptive decision-making. This leads to our second hypothesis:

> *Hypothesis 2:* Leaders with higher levels of neurological LSC (i.e., less connectivity in the frontal lobes in the alpha range) will demonstrate higher levels of adaptive decision-making.

# Method

## Participants

To test our hypotheses, we secured a sample with relevant experience in the same general domain of leadership (i.e., military leadership). We recruited a diverse sample of volunteer military leaders, seeking participants representing a span from low to high levels of experience, from an Army training base in the Eastern United States. The sample consisted of 103 leaders ranging in rank from officer cadet to major (87 male and 16 female; average age = 23.9 years [range of 19 to 39, *SD* = 5.9]; and with 4.2 average years of military leadership experience [range of 1 to 18, *SD* = 4.7]). There were 74 officer cadets in the sample, including 13 with previous combat experience as former enlisted personnel, along with 29 captains and majors with significant and recent combat experience. All participants had participated in tactical military training, such as combat simulations and field exercises.

## Procedures and Measures

Volunteers were solicited through announcements made during training classes. They were instructed to sign up for time slots, with two slots per hour available over a 2-week period. The sign-up sheet instructed them to report to a designated room for a "leadership study," but they were not provided any details as to the theoretical nature of the research. As the researchers were limited to one qEEG device and technician, when participants arrived at the designated room, they were randomly assigned to either the "psychometric only" or "brain mapping" protocol, each in a separate room. During any time slot in which only one participant signed up, that person was assigned to the brain mapping protocol to maximize the use of the EEG system. Of the 103 participants, 67 completed both the psychological and neurological protocols, the latter while wearing the 19 channel EEG system. Both groups proceeded through the same set of tasks that included, in order, medical prescreening (e.g., assessing past injuries, mental health, use of prescription drugs, and so forth, as needed for possible exclusion from sample), answering demographic and military experience questions (correlates of self-complexity), completing a standardized self-report role/attribute exercise to assess self-complexity psychometrically, and processing a military scenario to assess adaptive behavior, which was later expert-coded. The use of qEEG, self-report exercise, and externally coded responses provide a multimethod procedure to limit common method biases (Podsakoff et al., 2003).

**Psychological leader self-complexity measure.** We developed a standardized self-complexity measure for the specific military leadership domain using a combination of the paper-and-pen technique of Woolfolk and colleagues (Woolfolk et al., 2004; Woolfolk, Novalany, Gara, Allen, & Polino, 1995) and the free response format of Linville (1987). Consistent with Linville (1987), to limit demand characteristics, we did not provide participants with any leadership role labels but allowed them to produce leadership roles consistent with their identity in free response. Participants were asked to envision themselves as leaders of a unit in combat, and then list and provide a one or two sentence definition of the various roles that they saw themselves as possessing in that context. Requiring role definitions served to evoke deeper processing and thus activate in participants the attributes related to each role (Higgins, Van Hook, & Dorfman, 1988). Consistent with Woolfolk et al. (1995, 2004), participants were then provided with a number of pages (one page for each role that they defined), with each page containing 33 leader attributes listed in a column. These leader attributes were drawn from the referent structure developed by Hannah et al. (2010), which these researchers derived from a series of in-depth interviews with experienced tactical military leaders. From their grounded research, Hannah et al. (2010) discovered that these are primary attributes that enable leader effectiveness in a tactical level combat context, but they also proposed, based on self-complexity theory, that these attributes should be structured across various identity roles (i.e., self-complexity) to enable leaders to tailor their employment. It is important to note that the attributes drawn from this referent structure are not meant to be exhaustive, but only represent the general domain of interest (tactical military leadership), and they serve as a proxy for complexity in this domain.

Next to each attribute, participants were asked to "answer how important each attribute is to how you describe yourself in the role . . . in essence how important is that attribute to your self-concept in that role." The response used a 3-point scale: *not important* = 0, *important* = 1, or *very important* = 2. As practiced by Woolfolk et al. (2004), separate pages were used for each role to encourage participants to reflect upon how each attribute applies to a given role separately and more intently. For analysis, however, the columns from each page were collapsed by the researchers into a single matrix wherein participant scores create a roles × attributes matrix of data, with cell entries of 0, 1, and 2. The *h*-statistic (Attneave, 1959; Scott, 1969) is the measure of self-complexity that we used to analyze the matrix. Conceptually, *h* represents an index of the amount of independent dimensions underlying the set of attribute ratings. Participants would have a higher *h* score, for example, when they rate themselves as having more self-aspects (roles) and a greater differentiation of self-attributes between roles.

In the current study, a more differentiated leader would, for example, organize those attributes and abilities more associated with a role of tactical commander (e.g., those related to establishing purpose and control in their unit under stress) separate from those attributes associated with a role of diplomat (e.g., those related to mediating conflict between groups). A less complex leader may, for example, possess a limited set of roles as well as a less robust and less differentiated set of attributes across those roles (e.g., primarily possessing tactical commander attributes across a limited set of roles). Based on our hypothesis development, this less complex leader would be less adaptive and more likely to be limited to warfighter-oriented behavioral repertoires in response to leadership challenges, even though the situation may in fact call for a nonwarfighting (e.g., diplomatic) response.

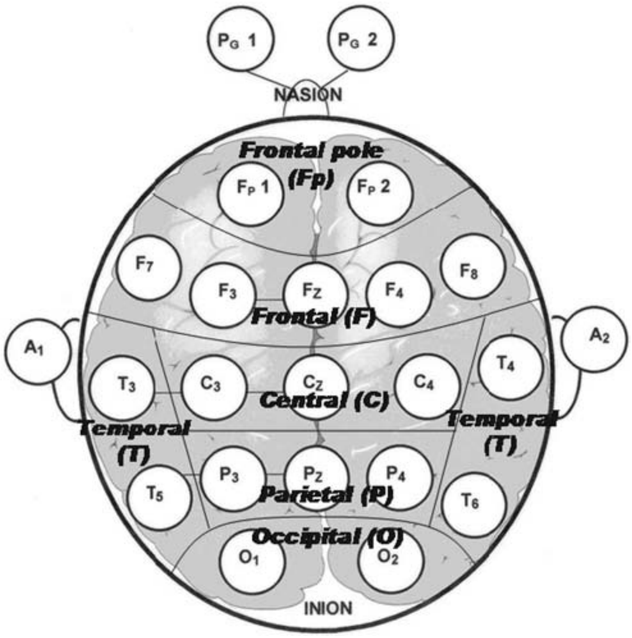

*Figure 1.* Scalp placement and labels for electrodes used in the International 10-20 system.

**Neurological leader self-complexity measure.** We applied electrophysiological measures derived from power spectral analysis of electroencephalography (also referred to as quantitative EEG or qEEG methodology) to develop a numerical index representative of leader self-complexity. The index corresponds to the average connectivity (limited to the alpha frequency range) across electrode pairs found in the frontal lobes of the brain, as defined below.

To obtain these neurological data, EEG electrodes were placed on the head at the 19 scalp locations specified in the International 10–20 system of electrode placement (Jasper, 1958). See Figure 1 and the Appendix for an overview of EEG electrode placement and methodology. Participants were seated in an upright position and encouraged to relax but to sit as still as possible and minimize eye movement (especially blinking). Data collection began when the observation of participants' raw EEG on the computer monitor indicated that eye and other movement artifacts were minimized.

An EEG segment of at least 3 min was recorded at a digitization rate of 128 Hz during an eyes-closed resting (but alert) condition for all participants. Each EEG record was visually examined and edited to remove artifacts while supported by the Neuroguide software (Applied Neuroscience, St Petersburg, FL), which maintains artifact rejection routines for eye movements, drowsiness, and instances where EEG voltage in any channel exceeds patterns that are typical of the participant's EEG. A resulting minimum of 60 s of artifact-free EEG was obtained for each participant. Split-half reliability tests and test–retest reliability tests were conducted on the edited EEG segments, and only when a record attained reliability greater than .95 was it kept for the ensuing qEEG spectral analyses.

As noted earlier, qEEG data collected in a baseline or at rest state represent a more stable view of brain structures by recording the brain's intrinsic activity (i.e., activity not directly related to a task, event, or stimuli), which may accurately reflect the capacity of an individual (e.g., Raichle & Snyder, 2007). In a sense, the at rest state would not be appropriate if the goal was to temporally track executive functions or memory encoding and retrieval activities per se (e.g., extrinsic response to a stimuli). However, the study of the intrinsic brain is preferable when the goal is to examine the underlying structures that might allow for more enduring brain functions, such as LSC.

Although several EEG metrics can be derived from brain electrical waves, in line with our a priori conceptualization, we operationalized connectivity by applying the EEG coherence construct in the alpha frequency range. EEG coherence is a statistical measure of the consistency of time or phase differences, and thus the magnitude of coupling between cortical areas (i.e., refers to the extent that parts of the brain are working together in a synchronous manner; Thatcher et al., 1986). It is based on the similarity and stability of electrical signals within a given frequency band across those areas (Nunez, 1981; Rappelsberger & Petsche, 1988). Coherence is equivalent to the percentage of variance accounted for and is often presented in the form of a percentage. For example, 90% alpha coherence indicates relatively high synchronous coupling between brain locations at this frequency, while 10% alpha coherence would indicate relatively low coupling or differentiation between the locations at this frequency. A number of studies have shown that coherence values are quite stable over time, demonstrating typical test–retest reliabilities that are greater than .90 (e.g., Corsi-Cabrera, Galindo-Vilchis, del-Río-Portilla, Arce, & Ramos-Loyo, 2007; Gasser, Jennen-Steinmetz, & Verleger, 1987; Thatcher et al., 1986).

The functional role of alpha frequencies (e.g., 8–12 Hz) is still debated in the neuroscience literature. Classically, it is considered as the brain's "idle rhythm," sort of a standby state that allows the system to return more rapidly to goal-oriented functioning when needed (Nunez, Wingeier, & Silberstein, 2001). Hans Berger (1929) found early on that alpha activity increases during eyes closed, especially at rest, and it decreases with eyes open (i.e., the "Berger effect"). As is the case in our research, several more recent imaging studies examining alpha waves have supported the notion of an activated rest state by describing a network of activation that is being diminished during goal-oriented tasks relative to no-task (Gusnard & Raichle, 2001; Greicius, Krasnow, Reiss, & Menon, 2003; Raichle et al., 2001). An examination of alpha waves in a rest state may thus provide an important marker of the underlying capacity for LSC.

In sum, to emphasize the neural regions that have been associated with the processing of aspects of the self, executive and memory functions, and complex cognitive processes of leadership (e.g., Craig, 2009; Devue et al., 2007; Mu & Han, 2010; Platek, 2004; Shi et al., 2011), we calculated a different alpha coherence value for electrode combinations in the frontal lobes (i.e., denoted as Fp, F, and C regions in the international 10/20 system, see Figure 1) that contained nodes in different subregions (i.e., Fp/F, Fp/C, F/C). Thus, the 10 electrodes in the frontal lobes (i.e., Fp1/2, F3/4, F7/8, C3/4, Cz, and Fz) produced 30 such combinations. We then averaged the coherence scores from the frontal lobes into a single coherence index to produce a measure of neurological LSC.

**Adaptive decision-making measure.** We examined the potential importance of LSC by assessing adaptive decision-making as a form of adaptive leadership performance. We measured adaptive decision-making by placing the participants through a four-part tactical military scenario. The scenario was developed by two West Point military leadership instructors (both with combat experience and 12 and 26 years of total military experience, respectively) specifically for this study to ensure it had content validity and presented participants with the key aspects of adaptive situations: changing situations, each with novel and ill-defined leadership challenges (Chan, 2000). Specifically, each part of the four-part scenario added progressively higher levels of ill-defined factors, which increased situational complexity and decision-making difficulty. The scenario is contextualized in terms of an international humanitarian relief mission in Africa in which the leader is in charge of a unit responsible for a security checkpoint designed to guard a food distribution site. In each of the four parts of the scenario, the situation progressively deteriorates, and more complex and ill-defined aspects are added in each part, whereby the participant is required to lead his or her unit to interact with hostile and nonhostile civilians, feuding warlords, enemy forces, the media, and eventually, the shooting down of a U.S. helicopter near the checkpoint.

We utilized a "freeze technique" (Endsley, 1995a) to query participants about their thinking in situ. Participants completed the four-part scenario, one part at a time. In each part, the participant received a piece of paper to read with that portion of the scenario printed on it, and when ready, he or she was instructed to verbally answer a short series of open-ended questions. Example questions included, "Describe how you assess the situation and identify what aspects of the situation stand out as most significant," "What kinds of information or intelligence have *not* been provided that would be helpful to you in assessing the situation and developing alternative courses of action?" "What factors are most important to your decision about what to do?" and "What alternative courses of action are you considering in formulating your decision about the downed helo?" Participant responses were audio-recorded, transcribed, and content-analyzed.

Content analysis is a valid way to tap individuals' underlying decision processes, since the language that they use reflects their cognition (Whorf, 1956; Winograd, 1983) and thus enables the researcher to infer cognitive schemas (Huff, 1990; Woodrum, 1984). We followed Winograd (1983) to ensure reliable and valid coding of the adaptive decision-making of the participants. A structured coding protocol was developed based on a literature review of military decision-making in tactical situations. Based on this review, three indicators were operationalized: (a) situational analysis, (b) decisiveness, and (c) positive action orientation.

*Situational analysis* reflected participants' demonstrated situational awareness and adaptive thinking, based on their perception and comprehension of the given environment, such as its shifting surface and structural features, and formulation of responses (Endsley, 1995a, 1995b; Matthews, Strater, & Endsley, 2004). Situational analysis also assesses the ability to effectively adjust one's thinking to the demands of unfolding events and changing circumstances and to apply one's prior expertise to new situations based on common structural elements (Pulakos et al., 2000, 2002; Smith et al., 1997). In the context of the tactical scenario, we assessed how well respondents adjusted their analysis as new information was presented in each new part of the changing scenario, enabling us to assess whether they adjusted their situational awareness and adaptive thinking and their ability to make timely and effective decisions regarding future events in the evolving environment (Endsley, 1995b; Pulakos et al., 2000, 2002). For example, when the situation deteriorated from a humanitarian assistance focus, to the negotiation between feuding warlords, and to conflict with hostile forces, we were able to assess if participants were able to perceive and comprehend the shifting features and apply prior expertise to the unfolding situation. Further, at two key points in the tactical scenario, participants were asked to make explicit decisions based on their situational analysis and to state what orders they would give to their followers. Thus, along with situational awareness, raters evaluated two decision criteria: *decisiveness* in terms of whether the participant identified a clear and well-articulated course of action to take, and *positive action orientation* in terms of whether the decision reflected purposive action to actively and effectively influence the situation.

A 3-point scale (*low* = 1, *moderate* = 2, or *high* = 3) was used to rate each of the three indicators (situational analysis, decisiveness, and positive action orientation) in each of the parts of the scenario, with ratings averaged across the parts for each participant. Coding was conducted by two independent raters outside the research team, each a former military officer with significant experience and expertise with the type of tactical situation used in our scenario. A training session was conducted to familiarize each rater with the indicators and to practice on sample participant responses. Practice coding protocols were discussed and more refined coding rules were developed to eliminate ambiguity in the coding rules. Each rater then independently coded each of the participant transcripts in randomized order. After initial coding produced a mean Cohen's kappa = .73, reflecting "substantial" interrater reliability (Landis & Koch, 1977, p. 165), discrepant scores between raters were identified, discussed and resolved using a consensus approach in a second iteration, ultimately achieving 100% reliability (Bullock & Tubbs, 1987).

**Mastery experience measures.** Leader adaptability is facilitated as leaders acquire experience within a general domain over time and create role sets and associated attributes that form the self-concept and its related components, such as KSAOs (Karaevli & Hall, 2006; Streufert & Swezey, 1986). Further, work experience has been associated with higher levels of performance (see Chan, 2000). Accordingly, we controlled for two experience indicators in our analyses when predicting adaptive decision-making to demonstrate that LSC contributes unique explanation in adaptation beyond simple experience. We used two measures of experience that we believed to be highly relevant to military tactical adaptive decision-making. Participants reported their (a) years and months of total military leadership experience and (b) whether they had combat experience.

## Results

Means, standard deviations and correlations for all study variables are shown in Table 1.

First, we assessed the relationship between our psychological and neurological measures of LSC on the one hand, and leader experience on the other. LSC is formed through experiential social learning as leaders establish roles and role sets to meet leadership task demands in a general domain. Therefore, both markers of LSC should correlate with leader experience. As shown in Table 1, both psychological LSC ($r = .15$, $p < .10$ and $r = .25$, $p < .01$) and neurological LSC (r = $-.34$, $p < .01$ and r = $-.29$, $p < .01$) are significantly related to military leadership experience and combat experience, respectively. It should be noted that negative correlation values stem from the fact that lower coherence values (i.e., differentiation or desynchronization) denote increased brain complexity. These findings help provide evidence of the construct validity of our LSC measures. Additionally, although psychological and neurological markers of LSC were derived using different methodologies and represent different or complementary dimensions of LSC (i.e., a psychometric assessment versus a biological capacity), both reflect forms of complexity, and as such, we expect these two markers to correlate, which was supported ($r = -.29$, $p < .05$).

## Hypothesis Testing

To test our hypotheses, we conducted a three-step multiple regression in predicting adaptive decision-making, as shown in Table 2. In the first step, we entered military leadership experience and combat experience as control variables. We then added our psychological LSC measure in Step 2a and our neurological LSC measure in Step 3. In a separate model, we entered our control variables with our neurological LSC measure (Step 2b) but without the psychological LSC measure. All models significantly predicted adaptive decision-making, and each successive step in the multiple regression analysis explained significantly more variance. In the model that included all control variables and predictors, we found that both predictors produced significant beta coefficients. Ultimately, the model that includes both LSC measures explained variance in adaptive leadership beyond what is explained by either traditional psychometric or neurological approach alone. In sum, Hypotheses 1 and 2 are supported.

## Supplemental Analyses

To examine the neurological LSC—adaptive decision-making relationship (Hypothesis 2) in more detail, participants were separated into a high neurological LSC group (operationalized as one standard deviation *below* the mean alpha coherence value for our sample), versus a low neurological LSC group (operationalized as one standard deviation *above* the mean alpha coherence value for our sample). This allowed us to also assess whether extremely high levels of neurological LSC in a nonclinical group of subjects (e.g., "normal") is undesirable, such that too much complexity deteriorates adaptive decision-making. The high neurological LSC (e.g., low frontal alpha coherence) group was composed of 14 individuals (mean alpha coherence = 39.60, $SD = 2.52$), while the low neurological LSC (e.g., high frontal alpha coherence) group was composed of 11 individuals ($M = 68.96$, $SD = 6.41$). A *t* test revealed a significant difference between the resulting adaptive decision-making scores ($t = 2.98$, $p < .01$) between high LSC ($M = 2.24$, $SD = 0.39$) versus low LSC ($M = 1.79$, $SD = 0.35$) individuals.

As a second supplemental test of Hypothesis 2, we discriminated participants into two groups based on their ratings on the adaptive decision-making measure and assessed their alpha coherence patterns. To depict this relationship graphically (see Figure 2), we used a module of the Neuroguide software to compare via *t* test the alpha coherence patterns of those identified as being the most adaptive decision-makers (1 standard deviation above the mean, $n = 14$), versus the least adaptive decision-makers ($n = 10$, those at least 1 standard deviation below the sample mean). The referent "brain" shown in Figure 2 is the high-adaptive group. The solid lines represent electrode combinations across which the most adaptive decision-makers have significantly less coherence (e.g., greater brain complexity) than those that are least adaptive, while the dotted lines show those connections where they have more coherence than the low-adaptive group. The intensity (i.e., width)

Table 1
*Correlations for Constructs in the Study*

| Variable | *M* | *SD* | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| 1. Military leadership experience | 4.18 | 4.67 | — | | | |
| 2. Combat experience | 0.39 | 0.49 | $.80^{**}$ | — | | |
| 3. Psychological LSC (e.g., *h*) | 2.48 | 0.89 | $.15^{\dagger}$ | $.25^{**}$ | — | |
| 4. Neurological LSC (e.g., frontal alpha coherence) | 48.56 | 10.71 | $-.34^{**}$ | $-.29^{*}$ | $-.29^{*}$ | — |
| 5. Adaptive decision-making | 1.86 | 0.44 | $.36^{**}$ | $.42^{**}$ | $.30^{**}$ | $-.35^{**}$ |

*Note.* LSC = leader self-complexity. $N = 103$, except for cells involving neurological LSC, where $N = 67$.
$^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$. Two-tailed.

Table 2
*Multiple Regression Analyses*

| Model | Standardized beta | $t$ | $R$ | $R^2$ | $R^2$ change | $F$ | $F$ change |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| Military leadership experience | .08 | 0.43 | .36 | .13 | .13 | 4.62$^{**}$ | 4.62$^{**}$ |
| Combat experience | .29 | 1.60$^{\dagger}$ | | | | | |
| 2a | | | | | | | |
| Military leadership experience | .09 | 0.51 | .43 | .19 | .06 | 4.87$^{**}$ | 4.82$^{*}$ |
| Combat experience | .23 | 1.26 | | | | | |
| Psychological LSC (e.g., *h*) | .26 | 2.20$^{*}$ | | | | | |
| 2b | | | | | | | |
| Military leadership experience | −.04 | −0.19 | .41 | .17 | .04 | 4.23$^{**}$ | 3.13$^{*}$ |
| Combat experience | .29 | 1.64$^{\dagger}$ | | | | | |
| Neurological LSC (e.g., frontal alpha coherence) | −.24 | −1.77$^{*}$ | | | | | |
| 3 | | | | | | | |
| Military leadership experience | .03 | 0.14 | .48 | .23 | .04 | 4.57$^{**}$ | 3.15$^{*}$ |
| Combat experience | .22 | 1.27 | | | | | |
| Psychological LSC (e.g., *h*) | .20 | 1.71$^{*}$ | | | | | |
| Neurological LSC (e.g., frontal alpha coherence) | −.22 | −1.77$^{*}$ | | | | | |

*Note.* LSC = leader self-complexity. Based on 67 observations. $R^2$ change tests for Models 2a and 2b are based on Model 1 as the baseline. $R^2$ change test for Model 3 is based on Model 2a as the baseline.
$^{\dagger}$ $p < .10$. $^{*}$ $p < .05$. $^{**}$ $p < .01$. Two-tailed.

of the lines indicates the level of significance of the t value of the between-group comparison. The thickest lines reflect differences at the $p < .001$ level, and the thinnest lines are at the $p < .05$ level.

The pattern supports the hypothesized relationship between the neurological marker of LSC and adaptive decision-making. Clearly, more complex frontal lobes in the alpha range suggest a greater capacity for adaptability. Interestingly, there also seems to be a noteworthy anatomical difference between the frontal lobes and the posterior cortical regions as depicted by the collection of dashed lines in the parietal and occipital lobes. These areas are responsible for integrating sensory information and managing the visual cortex—functions theoretically unrelated to self-complexity or adaptability. In that light, it is important to note that the alpha coherence in the frontal lobes is only marginally related ($r$ = –.18, $p < .10$) to posterior alpha coherence and that posterior alpha coherence is *not* correlated with adaptive decision-making ($r$ = –.04, *ns*), supporting the discriminant validity of our neurological marker of LSC.

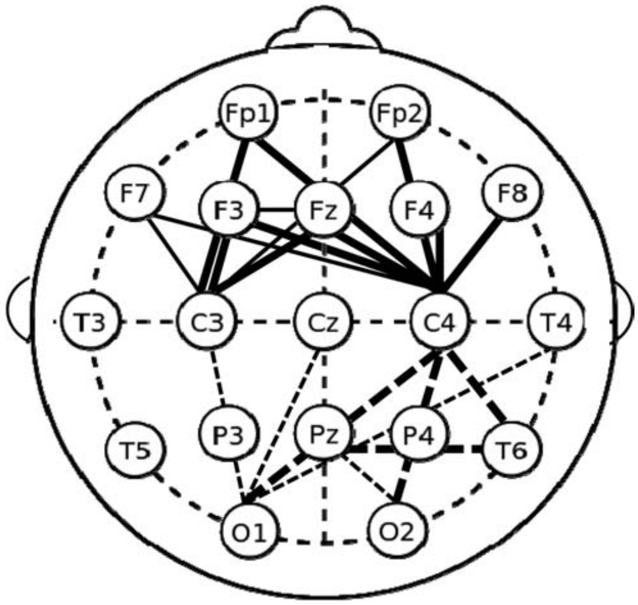

*Figure 2.* $t$ test comparison of alpha brain coherence between high and low adaptive decision-making individuals. Note that solid lines indicate less connectivity for high-adaptability compared to low-adaptability leaders; dashed lines indicate more connectivity for high-adaptability compared to low-adaptability leaders. Thick lines are significant at $p < .01$; thinner lines are significant at $p < .05$.

Additionally, it could be argued that the coherence pattern seen in the frontal lobes is indicative of a general activation pattern simultaneously occurring in other brain areas that are not theoretically related to neurological LSC. This would not be the case if the neural activity was isolated to the predicted area, without a concomitant pattern in theoretically unrelated regions. Following the original approach of tabulating alpha coherence values for electrode combinations of nodes in different subregions, we thus created 12 different alternate neural indexes emphasizing various brain regions besides the frontal lobes. An initial alternate index was made up of the nine electrodes not in the frontal lobes and the 23 coherence combinations that they produced. Various other indexes represented the temporal (left hemisphere, right hemisphere, and interhemispheric indexes), parietal, and occipital lobes. Other alternate indexes we tested involved multiple regions together. None of these alternate indexes proved to be significantly related to adaptive decision-making, and thus from a criterion validity perspective, our supplemental analyses suggest that they are not markers of neurological LSC.

Finally, it has been suggested that rhythms in different frequency bands might be coupled because of the broad recurrent connectivity among brain structures and associated functional operations (Schanze & Eckhorn, 1997). Indeed, in this study, coherence values in the alpha and beta frequency ranges are at least moderately correlated across the brain as a whole ($r = .54$, $p < .01$) and within subregions of the brain (i.e., $r = .57$, $p < .01$ in the left hemisphere; $r = .48$, $p < .01$ in the right hemisphere; and $r = .59$, $p < .01$ interhemispherically). Since beta band oscillations have also been detected in frontal lobe processes that are consistent with those included in the neurological LSC marker, including memory maintenance (Pesaran, Pezaris, Sahani, Mitra, & Andersen, 2002), we examined the relationship between the equivalent frontal lobe beta coherence index and the other primary constructs in the study. Unlike the alpha index, the beta coherence index is not significantly related to the psychological LSC marker ($r = –.15$, $p > .10$) or adaptive decision-making ($r = –.11$, $p > .10$). This pattern of correlations suggests that rhythms in the beta frequency band are not directly relevant to neurological LSC.

## Discussion

There is broad consensus that leaders, particularly those who operate in dynamic organizations, need to be adaptable to be effective in terms of how they address task and social challenges (e.g., Denison et al., 1995; Zaccaro, Foti, & Kenny, 1991; Zaccaro, Gilbert, et al., 1991). Scholars have put forth theories of leader complexity to attempt to describe what may underpin such adaptability (e.g., Hannah et al., 2009; Hooijberg et al., 1997; R. G. Lord et al., 2011). Yet these theories have not previously been tested. Further, the neurological basis for LSC has not been adequately considered, either theoretically or empirically. In this investigation, we employed techniques involving multiple sources and methods (Podsakoff et al., 2003) to assess the nature and outcomes of LSC.

In support of Hypotheses 1 and 2, both psychological and neurological markers of LSC were positively associated with demonstrated levels of adaptive decision-making on a complex leadership task, as rated by expert coders. More complex leaders demonstrated greater adaptive thinking, decisiveness, and positive action orientation as they addressed task demands and made leadership decisions in response to an evolving, four-part leadership scenario that escalated in complexity in each part. Specifically, results showed that the level of complexity of leaders' self-concepts related to a specific domain of interest (i.e., tactical military leadership) served to predict leader adaptive decision-making in that domain. Further, a lower level of EEG coherence (i.e., desynchronization or differentiation that characterizes brain complexity) in the alpha frequency range in the frontal lobes was also associated with greater adaptive decision-making. Moreover, the neurological marker explained variance beyond that of psychologically based LSC, suggesting that both forms of LSC underpin leader adaptability.

### Theoretical Implications

We extend prior work on leader complexity (e.g., Hooijberg et al., 1997) in three primary ways. First, we developed and operationalized, perhaps for the first time, a model of LSC, extending the recent work of Hannah et al. (2008, 2009, 2010, 2011) and R. G. Lord et al. (2011), and linking LSC to an important leadership outcome, adaptive decision-making. This focus on self-complexity in investigating leader complexity is based on the central role that the self plays in structuring leaders' various social roles and the knowledge, skills, abilities, and other attributes associated with those roles (R. G. Lord & Hall, 2005). This approach extends beyond leaders' general cognitive complexity (e.g., Streufert & Nagami, 1989; Streufert & Swezey, 1986) and proposes that leaders store expertise that is integrated with relevant goal systems, self-regulatory systems, and deeper metacognitive structures that have self-relevance and are tailored to leaders' social roles. Our results suggest that the self serves as an important interface between leaders' observable traits and behaviors and the deeper structures that drive their adaptive thoughts and behaviors (Hannah et al., 2009; R. G. Lord et al., 2011).

Second, we operationalized LSC drawing on methodologies used in clinical and social psychological work on self-complexity (e.g., Linville, 1987; Woolfolk et al., 1995, 2004). Extending such research, we assessed leader complexity through the differentiation in leaders' self-concepts related to their structuring of leadership roles and the attributes possessed in those roles. We demonstrated that this differentiation can be meaningfully captured through a self-complexity rating procedure, which served as a representative metric for leaders' levels of self-complexity. We are not aware of self-complexity methodology being applied to leadership phenomena. Thus, the current study offers new avenues for psychometric research on leader complexity and showed how measures can be tailored to a specified domain of leadership of interest (i.e., in the current research, military tactical leadership) to establish ecological validity.

Third, we established a neurological basis for leader complexity based on brain areas and functioning that was theoretically derived to be associated with the self, executive and memory functions, and complex cognitive processes of leadership. Specifically, we found that more complex leaders had lower alpha coherence throughout the prefrontal and frontal cortices (see Figure 2 for locations); specifically, the ventromedial-prefrontal cortex (particularly important for self-regulation), the dorsolateral prefrontal cortex (involved in attention processes, choice, and processing novelty), and the anterior cingulated cortex (monitors and guides behavior; see Chow & Cummings, 1999). Among other purposes that we described above, these regions drive perception, affect, self-knowledge, and self-regulation, thus providing leaders with the requisite complexity to comprehend, adjust to, and effectively engage with their followers and environment (R. G. Lord et al., 2011; Zaccaro, Foti, & Kenny, 1991).

We are aware of only one other published study that has assessed leadership using neuroscience, with the focus in that study on transformational leadership (Balthazard, Waldman, Thatcher, & Hannah, 2012). We believe that together these two studies demonstrate the utility of employing neuroscience to develop a deeper understanding of leaders' brain activity and therefore the "black box" of effective leadership (Senior, Lee, & Butler, 2011).

### Practical Implications

From a practical perspective, our results demonstrate that LSC is an important precursor to leader adaptive performance. Leader adaptability has often been cited as a key attribute of effectiveness (e.g., Denison et al., 1995; Zaccaro, Foti, & Kenny, 1991; Zaccaro, Gilbert, et al., 1991), yet little research has investigated its antecedents. Our results suggest that LSC could potentially be used for leader selection and to guide leader development efforts targeting greater complexity. Our employment of both psychometric and neurological LSC measurement techniques demonstrate that organizations can assess baseline levels of LSC and track leaders' development of LSC over time. Specific interventions, such as mastery experiences, career variety, forms of social learning and other techniques (e.g., Bandura, 1977; Karaevli & Hall, 2006; Kozlowski, Toney, Mullins, Weissbein, Brown, & Bell, 2001) could be employed with resultant changes in LSC tracked.

The neurological basis established for leader self-complexity may also provide some insights into leader development. There is a building canon of social neuroscience research that is providing an understanding of the functions and processes of various neural regions (for an overview, see Cacioppo et al., 2003). Through this knowledge, we can begin to understand how leaders' brains may develop and how that development can be accelerated. Further, through qEEG, fMRI and other techniques, such development can be tracked over time. For example, our results demonstrated that more complex leaders had lower alpha coherence in the prefrontal cortex, where executive functioning such as self-regulation largely occur. It may be possible, for example, to put leaders through exercises to develop their metacognitive ability (Dunlosky & Metcalfe, 2009), and then measure changes in prefrontal brain activity over time as they develop toward a normative index.

Another potentially important application of this work may be toward employing neuro-feedback techniques for leader development. Once a neurological norm (i.e., an "expert" profile) for LSC or other leadership phenomenon can be developed and validated, those norms can then be used through EEG neuro-feedback techniques for leaders to "train their brains," whereby leaders would modify the amplitude, frequency, or coherence of targeted neurophysiological dynamics of their own brains in response to feedback stimuli (Blanchard & Epstein, 1978; Cohen, 1975; Rosenfeld, 1990). Neuro-feedback techniques have been used successfully in training elite athletes (e.g., Crews & Landers, 1993), concert musicians (e.g., Egner & Gruzelier, 2004), and financial traders (see Peterson, Balthazard, Waldman, & Thatcher, 2008). We suggest that similar techniques could be applied to enhance leader effectiveness.

## Limitations and Suggestions for Future Research

A strength of this study is the multimethod approach used to formulate and test our hypotheses (Podsakoff et al., 2003). Yet, some limitations of this study deserve note. First, the sample and instrumentation focused on a specific domain of leadership (i.e., military), raising questions of generalizability pending further replications. Yet, the context-specificity of our investigation can be considered as a strength, since psychological LSC is domain-specific and should be assessed with a referent structure related to that domain (Goldsmith & Kraiger, 1997; Hannah et al., 2010). Thus, context needs to be taken into account when operationalizing psychological LSC. While neurological-based LSC is developed through unique experiences we propose that it is fairly stable at any point in time, and thus, may more readily generalize across contexts. Along these lines, an important avenue for future research will be to assess leaders' psychological complexity in more than one domain in which they may operate (e.g., for a military officer who is also a church elder to assess tactical leadership, as well as also clergy leadership), and then assess how, along with neurologically based LSC, it influences how participants operate within and across each domain based on the varying levels of complexity that they have for each domain.

Second, all psychometric measures used to operationalize complexity have limitations. To increase our confidence in the validity of the psychological LSC measure, we based it on a referent structure (Goldsmith & Kraiger, 1997) that was validated by Hannah et al. (2010) across three samples of tactical military leaders, raising our confidence that the attributes were relevant to our sample. Further, we sought to combine the strengths of Linville's (1987) free response format (i.e., by allowing leaders to conceptualize their own roles) and Woolfolk et al.'s (1995, 2004) structured attribute format. Yet there are limitations inherent in each of the various methods of measuring psychological LSC, and due to the demands that complexity ratings place on participants (e.g., the current study required participants to rate 33 attributes across five roles = 165 items), items must be limited. Thus, all techniques provide only a representative assessment of the content and differentiation of the self-concept (Woolfolk et al., 2004).

Further, with the goal of linking complexity to leader adaptability, we treated experience as a control variable. However, in future research, experience could also be considered as an antecedent in its own right. For example, we conducted supplemental analyses that revealed that the relationships between military leadership experience as well as combat experience and adaptive decision-making were mediated by psychological complexity. It could be that experiences of this nature help to shape the leader's psychological complexity, which in turn, affects adaptive decision-making abilities. The cross-sectional nature of our data precludes definitive statements regarding causality of this mediation, although researchers might consider such possibilities.

There are similar limitations pertaining to neurological variables; not as much on the generation of measures, but rather on the selection and use of variables. In this initial investigation, based on multiple prior studies that examined the self and neural complexity issues (e.g., Goldberg & Bilder, 1987; Vogeley et al., 1999), we chose a priori to broadly inspect coherence in the frontal lobes and to restrict our analysis to the alpha frequency band (e.g., Jensen, Gelfand, Kounios, & Lisman, 2002; Klimesch, 1999; Klimesch et al., 1996, 2001; Stam, van Cappellen van Walsum, & Micheloyarmis, 2002). A more exploratory or broad approach that would include (a) more specific brain regions chosen on the basis of targeted cognitive processes, (b) other frequency ranges, and (c) other EEG variables, might explain greater variance in adaptive leadership. For instance, measuring activity in the parietal cortex would be crucial if capacity for computation is conceived to be important (Dehaene et al., 1999), or if assessment of probability (Ernst et al., 2004; Platt & Glimcher, 1999; Shadlen & Newsome, 2001) is part of the decision-making algorithm. Furthermore, the anterior cingulate cortex has been associated with processes of uncertainty (Critchley et al., 2001; Elliott et al., 1999) and could be useful if the decision-maker needs to keep track of successes and errors over time (Carter, Botvinick, & Cohen, 1999; Knutson, Fong, Bennett, Adams, & Hommer, 2003). Further, temporal lobes have an important role to play in memory management processes (e.g., Squire & Zola-Morgan, 1991).

Although very appropriate for LSC, alpha represents only one range. The theta and gamma bands (Nyhus & Curran, 2010) have recently been discussed as having a functional role in episodic memory processes. Further, alternative EEG variables such as power (Klimesch, 1999) and phase shift/lock (Thatcher et al., 2005) have been shown to be associated with cognition and memory performance in other investigations of brain complexity. That being said, our findings are in accordance with existing neurological assessments of the self, and the theoretically derived neural index that we produced appears to have construct validity based on correlates and outcomes in a nomological network.

Finally, the complexity of the current self is distinct from the complexity of the future or possible self (Niedenthal, Setterlund, & Wherry, 1992). When a leader envisions a future self, it creates motivation for development, targeted at that ideal possible self (R. G. Lord & Brown, 2004). This suggests that future research may extend our work, which has assessed leaders' current selves, to investigations of possible selves. Further, leader complexity has been proposed to be a key component underlying leaders' levels of developmental readiness by providing the capacity to better understand and make sense out of developmental experiences (Hannah & Avolio, 2010). Accordingly, how leaders construe their future self, as well as the neurological underpinnings for that construal, have logical implications for accelerating leader development.

## Conclusion

The cognitive revolution in leadership and organizational studies has brought greater attention to the mental processes of leaders to explain leader behaviors and effectiveness. To date, however, this revolution has been limited largely to conjecture of what occurs inside the "black box" of leaders. A commensurate revolution is needed in the methodology used by leadership researchers. Overall, our research represents a multidisciplinary and multimethod approach to the conceptualization and assessment of LSC, thus entailing a fusion of the leadership and neuroscience fields. We envision the possibility of such neuroscience research to revolutionize approaches to the assessment and development of the complexity of leaders as key factors in realizing their adaptive performance. The current study takes a step in that direction.

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## Appendix

## Reporting on the Brain's Electrical Activity

The human brain is made up of hundreds of billions of microscopic elements called neurons that use chemical messages to regulate electrical activity throughout the brain. The brain communicates to itself and with the body by means of these electrical changes. The purpose of this Appendix is to provide a summarized description of how the brain's electrical activity is reported upon via qEEG analyses.

### The International 10-20 System

In our study, the EEG was recorded from 19 scalp locations based on the International 10-20 System (see Figure 1) of electrode placement originally developed by Jasper (1958). The system divides the skull into proportional distances based on four prominent landmarks: dent of the nose (nasion), protrusion in the back of the head (inion), and preauricular points directly in front of each ear. Labels reflect underlying brain areas: Fp for frontal pole, F for frontal, P for parietal, C for central, T for temporal, and O for occipital. Sites are numerically sequenced from midline, which is set as zero or Z, with odd numbers on the left hemisphere alternating with even numbers on the right (see Figure 1). The resulting set of electrode placements is a standardized method used to describe the location of scalp electrodes and the corresponding cortical (brain) anatomy. For example, in the International 10-20 System, T4 refers to the right temporal lobe just above the ear, O1 refers to the left occipital lobe at the back of the scalp, and so forth. Our study focuses on the 10 electrodes that sense activity in the frontal lobes, including the prefrontal areas (e.g., Fp1/2, F3/4, F7/8, C3/4, Cz, Fz).

Electrode locations have been shown to reflect accurate voltage recordings of the correct underlying anatomic structures (e.g., Thatcher et al., 1986, 2012). With the system in place and the ability to distinguish and plot different wave ranges, researchers can identify normal and abnormal patterns in brain electrical activity. Selected EEG features from across different brain regions can quantify the organization within the brain and identify "signature patterns" of brain activity that can predict traits and behaviors.

### EEG Coherence

The measure of connectivity between a pair of electrodes is given as a percentage that is labeled as one of the 171 possible combinations. That is, Fp1T4 = .29 would state that the connectivity between Fp1 (prefrontal lobe in the left hemisphere) and T4 (midtemporal lobe in the right hemisphere) is 29%. This measure is referred to as "coherence" in the neuroscientific literature (e.g., Thatcher, North, & Biver, 2005). Coherence is a measure of the variability of time differences between two time series. The Fourier transform provides a direct relationship between the time and frequency domains and represents time difference as a phase difference or phase angle. If the phase angle is stable and constant over time (i.e., phase locked), then coherence = 100% and if time differences between two time series varies completely from moment-to-moment, then coherence = 0%. Coherence is often interpreted as a measure of "coupling" and as a measure of the functional association between two brain regions (Nunez, 1995; Thatcher, Krause, & Hrybyk, 1986; Thatcher et al., 2005). Coherence is a sensitive measure that can reveal subtle aspects of the network dynamics of the brain which complement the data obtained by spectral analyses of specific electrodes.

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