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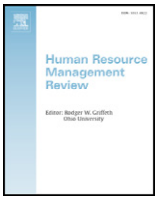

Leveraging neuroscience for smarter approaches to workplace intelligence

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ABSTRACT

The aim of this paper is to provide an overview of neuroscience research related to adult intelligence and explore the implications of adopting an organizational neuroscience perspective for workplace research and practice. We argue that neuroscience will have several important consequences. First, it will force us to refine our definition of what intelligence is and is not. Second, this new conceptualization of intelligence provides a number of new measures of intelligence that could be more valid than current measures depending on the specific job demands under consideration. Lastly, this new perspective sheds new light on a number of situational factors that limit an individual's ability to utilize their full intelligence capabilities.

Understanding human intelligence has been and continues to be one of the most fascinating and frustrating scientific pursuits. This is especially true in Industrial and Organizational Psychology (I/O) and Human Resources (HR) research and practice where measures of intelligence have been widely studied and represent the most valid existing predictor of job performance (e.g. Schmidt, 2002; Schmidt & Hunter, 2004). In addition, intelligence has also been positively associated with other important outcomes like leadership and career success (Judge, Colbert, & Ilies, 2004; Judge, Higgins, Thoresen, & Barrick, 1999). Going a step further, intelligence has also demonstrated positive associations with broader outcomes like improved health and life expectancy that are also relevant to the work domain (Gottfredson & Deary, 2004).

Meanwhile, there has been a growing unease with the use of traditional general intelligence measures in employee selection. This sentiment is largely due to social and legal repercussions from observed group differences in intelligence scores across different races and cultures. Due to concerns with adverse impact, organizations have reduced their use of formal intelligence measures (Schmidt, 2002). Paradoxically, this has almost certainly increased employers' reliance on weaker proxies for intelligence, such as a candidate's alma mater, which likely worsens rather than reduces adverse impact in selection.

A number of factors have made it difficult to defend intelligence testing in the legal courts and popular media. These include a reliance on the psychometric approach (Goldstein, Scherbaum, & Yusko, 2009) and the lack of a strong theoretical foundation for intelligence measures (Kaufman, 2000; Scherbaum, Goldstein, Yusko, Ryan, & Hanges, 2012; Thorndike, 1997). Given that intelligence is inextricably linked to the brain, neuroscience should provide a logical theoretical underpinning for I/O and HR research and practice at the brain level of analysis (Becker, Cropanzano, & Sanfey, 2011). Therefore, a primary purpose of this article is to provide an overview of the current state of neuroscience research regarding the biological basis of intelligence and to explore its implications for future I/O and HR research and practice. Our purpose is not to perform a detailed review of any one area or to take sides in ongoing debates regarding intelligence, but rather to highlight broader findings and themes that inform issues that are relevant to organizations. To that end, we will first propose a revised working definition of intelligence. Then we will summarize the dominant psychometric frame-

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works of intelligence and explore the neuroscience evidence related to each. Lastly, we will discuss a number of important implications for I/O and HR research and practice that arise from incorporating a neuroscience perspective of intelligence.

1. Toward a more precise definition of intelligence

The neuroscience perspective of workplace intelligence dictates a narrower, theoretically-based definition of intelligence. Much of the current confusion and controversy around intelligence in organizational settings can be traced to the long standing perspective of intelligence put forth by Thorndike (1921) that intelligence is simply whatever intelligence tests measure. While the empirical (i.e., psychometric) approach to intelligence has been and will continue to be useful, a more theoretically based approach will be necessary to advance the intelligence research agenda (Kaufman, 2000; Scherbaum et al., 2012; Thorndike, 1997). To this end, we advocate defining intelligence as the biological ability to reason, solve problems, think abstractly, and learn quickly (Gottfredson, 1997). While this definition is not entirely new, a neuroscience perspective refines it by suggesting a number of distinctions. First, we can say with confidence that intelligence relies heavily on the conscious application of brain resources to solve practical problems. This does not suggest that intelligence lies in a single brain region or process, or that unconscious processing does not play a role in intelligent behavior. Rather, neuroscience findings suggest that intelligence relies heavily on recognizing a problem and consciously directing and maintaining available brain resources to attempt to solve it. This conscious direction and maintenance capability of the brain is referred to as executive function and the neuroscience literature reveals that it is a limited and variable brain resource. This suggests that individuals can differ in both intelligence resources and in their ability to employ these resources. We will take this issue up in greater detail later. A key distinction however is that intelligence occurs primarily within conscious awareness and through deliberate attention and direction.

In addition, we propose that it is important to differentiate between intelligence capacity and realized intelligence. By this we mean that one's intelligence capacity, as measured by intelligence tests, may differ significantly from their demonstrated intelligence on practical problems encountered in real-life situations. As we will show, specific biological and genetic factors are reliably related to individual differences in intelligence capacity (Deary, Penke, & Johnson, 2010). At the same time, biological, environmental, and situational factors can limit the realized intelligence observed in an individual or group. Intelligence research in the workplace would be well served by acknowledging that measured intelligence is not always the same as realized intelligence. This distinction would help account for and incorporate the perplexing but consistent findings of group differences on measures of intelligence. Notably, it suggests that direct comparisons between unique groups on the basis of general intelligence measures are ill-advised.

Unfortunately, the basic neuroscience of intelligence capacity is relatively immature and does not currently allow us to reliably measure biological capacity in a way that would be adoptable in the workplace. It does, however, suggest a number of measures that are related to specific cognitive capacities and functions and potentially smaller score differences between groups. In addition to individual differences in realized intelligence, this conceptualization also suggests that situational conditions can produce within person differences between intelligence capacity and realized intelligence. For example, mental stress may prevent people from efficiently employing their full cognitive resources. Before exploring these ideas further, we will first provide a brief introduction to the neuroscience of intelligence and the importance of the neuroscience perspectives for organizational research and practice.

2. Psychometric frameworks of human intelligence

We begin by briefly summarizing the Cattell–Horn–Carroll theory of intelligence (CHC theory) (McGrew, 2005) which integrates two prominent psychometric-based models of human intelligence: Carroll's (1993) three-stratum hierarchical model of intelligence and Cattell's (1943) and Horn's (1976) fluid-crystallized intelligence model. The CHC theory proposes a conceptualization of human intelligence in terms of a hierarchical three-level intelligence structure. Level three represents the general intelligence factor *g*. There is a long-standing debate about the presence or absence of this higher-order general intelligence factor that has proven intractable using traditional factor-analytic approaches in psychometric research (McGrew, 2009; Van der Maas et al., 2006). For example, it has been debated whether the positive manifold (i.e. the strong correlation between tests of seemingly unrelated cognitive abilities) is due to an underlying general intelligence factor or due to other factors such as mutually beneficial interactions between cognitive processes during development (Van der Maas et al., 2006).

Level two represents so-called broad abilities that are important for human cognition including sensory modalities such as visual, auditory, and olfactory abilities but also short- and long-term memory and fluid reasoning and comprehension knowledge. The latter two are particularly important as they represent the distinction between fluid intelligence (fluid reasoning) and crystallized intelligence (comprehension knowledge). The fluid component of intelligence refers to analytical (inductive and deductive) reasoning and novel problem solving abilities. Fluid intelligence relies on mentally taxing, deliberate, and controlled cognitive processing that is thought to be largely innate and thus biologically determined. In contrast, the crystallized intelligence component refers to the accumulated knowledge and skills derived from a lifetime of education and experience. Crystallized intelligence, which includes knowledge of specific cultural concepts, vocabulary, reading, and arithmetic skills, is the result of socialization and acculturation and thus strongly affected by environmental factors and education as well as one's innate ability to store and retrieve this information. There is often a strong relationship between fluid and crystallized intelligence since individuals who are more effective and efficient at problem solving will typically also acquire more crystallized intelligence and vice versa.

Finally, level one represents numerous more narrow abilities that form the basis of the broad abilities at level two. It is important to point out that while broad and narrow abilities have been shown to directly predict intelligence related outcomes such as school achievement (e.g., Floyd, Keith, Taub, & McGrew, 2007), the effect of *g* is often indirect. McGrew (2009, p.5) explained this by arguing that “g′s influence may be best understood as an indirect effect mediated by broad and narrow abilities”.

While the integration of Carroll's and Cattell and Horn's models into the CHC framework has abated many controversies in the field of human intelligence, we believe that I/O Psychology has much to gain from an expanded theoretical conceptualization of intelligence that incorporates a cognitive neuroscience perspective. Neuroscience intelligence research can move the CHC theory "beyond the mere description and cataloguing of human abilities, to provide multi-lens explanatory models that will produce prescriptive hypotheses" (McGrew, 2005, p. 172). From this perspective, it is clear that the brain performs cognitive tasks by recruiting a network of regions that provide a variety of functions and capabilities. For example, fluid intelligence and crystallized intelligence recruit networks that have significant overlap, but each also requires some specific capabilities that are provided by unique brain regions and networks. A cognitive neuroscience approach is well suited for research and practice in I/O and HR because it helps us to think differently about workplace intelligence and also suggests new intelligence measures the can be adapted to the workplace.

This new conceptualization of intelligence suggests that organizational researchers can draw from one, two, or all three levels of the CHC framework to develop theoretical arguments of how intelligence impacts the workplace. It is important, however, that they precisely align their arguments with the specific characteristics of each level and address how differences between the levels could affect their predicted results. Nonetheless, there will be some situations where a focus on a specific level will be important. For example, if a particular work task requires an exclusive degree of fluid or crystallized intelligence then a corresponding measure should be more predictive than a general intelligence measure. Likewise, the characteristics of the employees being considered may dictate the choice of appropriate level of analysis and measures as well. For example, if the employees in question were older, then we would expect that differences between fluid and crystallized intelligence would need to be accounted for by a heightened focus on level two of the framework.

It is important to point out that the neuroscience perspective is not inconsistent with previous I/O and HR research. Rather, it confirms the validity of existing measures and the body of empirical research on intelligence in the workplace even as it highlights some of its shortcomings. Moving forward, it also suggests that other measures from neuroscience and general psychology, such as those that test fluid intelligence and working memory, could be more valid and useful than current measures and proxies for organizational applications. We will take up this topic in greater detail in the next section of the paper.

3. The neuroscience approach to intelligence

In neuroscience, intelligence is investigated from a brain functioning perspective using a variety of techniques to identify the brain systems and processes underlying higher-order cognition. We should be clear that we endorse a very broad and inclusive definition of neuroscience. While functional magnetic resonance imaging (fMRI) currently dominates the headlines, we believe that other methodologies such as electroencephalography (EEG), transcranial magnetic stimulation (TMS), genetics, pharmacology and neurotransmitters, and neuroanatomy studies will all inform our quest for improved theoretical and practical accounts of human intelligence (For an overview of these methods and additional references, see Becker & Menges, 2013). We acknowledge that these methods may appear daunting at first, and some like fMRI and TMS may be beyond the realm of possibility for all but the most intrepid organizational researchers. Others like EEG and genetics are more approachable and have already been adopted in organizational contexts (e.g., Ilies, Arvey, & Bouchard, 2006; Waldman, Balthazard, & Peterson, 2011). More importantly, none of the research or findings from neuroscience is so complicated that it cannot be digested and incorporated into any stream of organizational research. Specific to the current topic, the neural level of analysis that is common to all these methods allows researchers to make and test specific hypotheses related to intelligence in organizational settings. In the next section we will review some of the existing neuroscientific evidence with regard to the CHC framework.

Evidence for broad abilities represented at the second level of the CHC framework comes from studies of the neurobiology of intelligence suggesting that there are clear structural distinctions between crystallized and fluid intelligence within the brain (Nisbett et al., 2012). This view is largely based on three bodies of research. First, a large number of fMRI studies have shown that tasks differing in the amount of fluid versus crystallized processing recruit different networks of brain activity, even while there are some regional overlaps. It is worth noting that these findings have shown considerable variability between studies, yet conclusive commonalities have emerged. The strongest of these has been the prominent role of the prefrontal cortex (PFC) in fluid intelligence (Jung & Haier, 2007). In addition, the anterior cingulate cortex (ACC) has been shown to play a key role in the interface between fluid intelligence and emotional responses to environment challenges (Blair, 2006).

There has also been substantial imaging work into decomposing fluid intelligence into lower level processes that rely on unique brain regions and networks and accomplish different aspects of cognitive processing. While this research is just getting started, it suggests that fluid intelligence relies on at least three distinct sub processes. First, working memory provides for the maintenance of information for manipulation and immediate recall. Second, executive function provides for attentional control and task switching. Lastly, there has been growing evidence for the importance of managing abstraction and cognitive decoupling in fluid intelligence (Cosmides & Tooby, 2000; Stanovich, 2006).

While imaging evidence for structural differences between fluid and crystallized intelligence continues to grow, some of the most compelling evidence for the distinction between these two broad abilities comes from two other research areas. The first involves studies of individuals who suffer lesions or traumatic brain injury in their frontal lobes. There is consistent evidence that post-damage, these individuals demonstrate much lower performance on measures of fluid intelligence, at the same time their scores on crystallized and general intelligence tests remains largely unchanged from before the injury (Duncan, Burgess, & Emslie, 1995; Roca et al., 2010). Research on aging also supports dissociation between fluid and crystallized intelligence and consistently finds that the frontal lobes are the first brain region to show functional and structural degradation with advancing age. These declines in frontal lobe function are accompanied by lower performance on measures of fluid intelligence, while scores on measures of crystallized and general intelligence do not show corresponding declines (Glisky, 2007; Salthouse, Atkinson, & Berish, 2003).

Neuroscience research provides not only evidence for the existence of clearly distinguishable broad abilities represented at the second level of the CHC framework but also for the general intelligence factor *g* represented at the first level. As we alluded to earlier, despite some differences in the neural networks that are activated during fluid and crystallized tasks there are also as many commonalities (Colom et al., 2009; Jung & Haier, 2007). For example, Duncan et al. (2000) observed in a positron emission tomography study that during the performance of intelligence tasks neural activations were prominent in the lateral prefrontal cortex. Related evidence implicating prefrontal brain regions, including the dorsolateral prefrontal cortex (DLPFC), in tests of general intelligence comes from neuroimaging studies (see Jung & Haier, 2007 for a review) and from theoretical work (Kane & Engle, 2002).

This link between general intelligence and DLPFC is particularly interesting given the crucial role of the DLPFC in working memory and executive functions (Curtis & D'Esposito, 2003). Working memory is a cognitive system that focuses attention and temporarily maintains and manipulates information necessary for the performance of complex cognitive activities such as thinking, reasoning, and decision making (e.g., Baddeley, 2012). The capacity of a person's working memory has been shown to be an important predictor of general intelligence (Cowan, 2001). Theoretically, working memory capacity has generally been more closely tied with fluid intelligence (Kane & Engle, 2002). Psychometrically however, the correlations between measures of working memory, general, fluid, and crystallized intelligence in normal working age adults are so high as to bring into question whether they can be reliably differentiated. Colom, Rebollo, Palacios, Juan-Espinosa, and Kyllonen (2004) reported a mean structural coefficient of 0.96 between working memory and general intelligence. Comparable results were obtained by a number of other studies (e.g., Ackerman, Beier, & Boyle, 2002; Colom, Abad, Rebollo, & Chun Shih, 2005; Oberauer, Schulze, Wilhelm, & Süß, 2005). Other work has shown that despite sharing a common factor, fluid and crystallized intelligence can be statistically differentiated (Dang, Braeken, Ferrer, & Liu, 2012). While this debate is not likely to be resolved in the near future, findings from neuroscience also provide insights into the theoretical basis for a common factor in intelligence.

For one, it is clear that intelligence is highly heritable across generations (Deary et al., 2010; Nisbett et al., 2012). While a thorough treatment of this topic is beyond the scope of this paper, we will briefly discuss several recent advances in this regard that have important implication for the workplace. First, molecular genetics research attempting to identify specific genetic markers that predict intelligence have been largely unsuccessful (Need et al., 2009; Payton, 2009). However, researchers have concluded that the heritability of intelligence, as in other complex phenotypes, involves many genetic variants related to intelligence that can be passed down from parents to children (Deary et al., 2010). Each variant has a small individual effect and many potential combinations exist that can produce higher intelligence. As a result, it is unlikely that a simple genetic test for intelligence capacity will be available in the foreseeable future. More germane to the existence of an intelligence common factor, there do seem to be links between genes and differences in brain structure and function (Pol et al., 2006; Posthuma et al., 2002). Therefore, in our view, researchers would be better served by investigating observable effects produced by these genetic influences within the brain, rather than searching for a silver-bullet genetic selection test.

Along these lines, recent neuroscience research has proposed and tested a number of theoretical foundations for a common intelligence factor. Brain volume represents one such potential common factor. Surprisingly, studies suggest that more intelligent people do indeed have larger brains. A meta-analysis by McDaniel (2005) found a positive correlation between brain volume and intelligence ($r = 0.33$), indicating that within the population about 10% of the variance in intelligence can be explained by differences in brain size (Toga & Thompson, 2005). There is also evidence that size also matters for grey matter volume in specific brain regions (Colom et al., 2009; Jung & Haier, 2007). These investigations have also revealed positive correlations between white matter (nerve cells that transfer information between regions) volume and intelligence (Posthuma et al., 2002; Yu et al., 2008).

In related work, there is evidence that measures of brain efficiency and transmission speed might also produce global improvements in brain function (Neubauer & Fink, 2009). Caryl (1994) reported a positive correlation between brain event-related potentials (ERPs) and higher intelligence. ERPs provide a measure of processing speed in the brain by measuring how fast the electrophysiological activity in the brain changes in response to specific stimuli. The intelligence-related differences in stimulus processing observed by Caryl have been interpreted as providing evidence that more intelligent brains function at a higher speed than normal brains (Deary & Caryl, 1997). Related results were obtained by Reed and Jensen (1992) who demonstrated a modest correlation between intelligence level and neural conduction speed, suggesting that neural impulses are transmitted at a faster speed in more intelligent individuals.

Together, these findings suggest that genetic factors may produce general improvements in brain organization and function that likely produce global improvements in brain functions. From this perspective it should not be surprising that a general factor of intelligence emerges empirically. More to the point, this bigger, faster, better brain factor likely conveys advantages in all aspects of brain and nervous system function, or, in the words of Higgins, Peterson, Pihl, and Lee (2007, p. 315) “Larger brains have larger prefrontal cortices; larger brains with larger prefrontal cortices have thicker axons; brains with thicker axons are faster; larger brains with thicker, faster axons have an advantage in terms of cognitive function.” This new insight helps to better interpret associations between general intelligence and a host of life outcomes and suggests that many of these relationships could be due to an overarching common factor and have little to do with intelligence per say.

The application of brain size and efficiency measures in practical settings seems unlikely in the near future. Nonetheless, their application in I/O research presents a number of interesting opportunities to refine our theoretical models of intelligence. In a promising first step, Higgins et al. (2007) added a physiological domain consisting of brain volume, prefrontal volume, and neural transmission speed to Carroll's (1993) three stratum model. We anticipate that intelligence scholars will continue to integrate psychometric and neuroscience research to build new and more comprehensive models of intelligence in the workplace.

In the remainder of this article, we will introduce additional topics where we believe neuroscience can inform and advance future intelligence research and practice in the workplace. First, we will discuss the potential for adapting neuroscience-based measures of intelligence for I/O/HR research. Lastly, we will discuss a number of factors that likely moderate how intelligence is realized in the workplace.

4. Measures of intelligence inspired by neuroscience

In the context of I/O psychology and HR, existing measures of intelligence are reliable, if imperfect predictors of numerous work outcomes of interest (Judge et al., 1999; Schmidt, 2002). However, being content with current intelligence measures sends the message that these predictors are good enough (despite validity concerns) so why push for better (Murphy, 1996; Scherbaum et al., 2012). Moreover, it has been argued in the I/O literature that new measures of intelligence have yet to be investigated adequately (Ones, Dilchert, Viswesvaran, & Salgado, 2010). We believe that a neuroscience perspective suggests a number of intelligence measures that have much to offer to I/O and HR research. Organizations could have much to gain from employing specific intelligence measures. More precisely, we argue that developing new measures of intelligence has the potential to improve upon the knowledge base of workplace intelligence in three ways.

First, new measures will improve the organization literature regarding intelligence by updating past results. Many of the I/O and HR studies involving intelligence were conducted many years ago. Murphy (1996) and Scherbaum et al. (2012) propose a number of possible explanations for the relative scarcity of current intelligence research compared to prior decades. Second, by exploring new measures we can refine and test our new theoretical conceptualizations of intelligence at work. For example, by going beyond general intelligence, we might identify additional relevant variables that help predict or explain how a specific type of mental capacity is important to effective employees and organizations. In addition, new measures may help to address the issue of adverse impact in selection. Results for existing intelligence measures consistently show subgroup differences across different races and cultures (Goldstein et al., 2009; Hough, Oswald, & Ployhart, 2001; Ones et al., 2010). As we discussed earlier, these differences may result from disparities between realized intelligence and intelligence capacity. They may also be due to the language demands of some traditional measures among other possibilities.

In the following sections, we will introduce a number of measures of intelligence that directly assess different mental capacities and abilities based on evidence from neuroscience research. These measures and often employ numbers, geometric figures, patterns, and pictorial representations of information that should show fewer language based differences. More precisely, we will discuss three categories of measures including (1) measures of working memory capacity, (2) measures of specific executive functions, and (3) measures of fluid intelligence. These measures have all been shown to be reliable predictors of performance on a variety of intelligence-based tasks and tests. Moreover, while the development of many traditional intelligence tests (such as the Wonderlic Personnel Test or the Scholastic Aptitude Test) were by and large data driven (Conway, Macnamara, & Engel de Abreu, 2012), the measures discussed here were instead motivated by established psychological and biological theories and neuroscience research. On the surface, some measures may not appear to be directly related to neuroscience. These have been included when they serve as suitable proxies for neurocognitive measures, or where neuroscience provides new insight into the interpretation of these measures. An added benefit for I/O and HR is that these measures could be readily adapted for application in the workplace. By adopting these more basic measures now we will be poised to adopt and interpret additional neuroscience measures of intelligence that are more technologically complex in the future.

The following section also demonstrates that incorporating a neuroscience perspective to enhance selection procedures does not always require the application of complex neuroscience methods. Evidence from neuroscience confirms that executive functions and fluid intelligence are unique components of general intelligence. Job design analyses indicate that some occupations require a higher degree of fluid intelligence or other executive function more so than general intelligence. Therefore, these more specific tests should be better predictors of job performance than tests or proxies of general intelligence. In addition, more specific measures of intelligence are also less likely than traditional measures to exhibit adverse impact across languages or cultural groups (Neisser et al., 1996). In this case, the best measures of specific mental capacities or executive functions currently available often come from general psychology and do not require any technologically advanced neuroscience methods. As a result, the adoption of these tests into selection procedures, despite being based on a neuroscience perspective, could be accomplished relatively easily.

4.1. Measures of working memory capacity

As explained above, working memory capacity (WMC) is a strong predictor of general intelligence. Further, there is a strong biological and brain based basis for individual differences in WMC (Kane & Engle, 2002). Measures of WMC typically consist of tasks that require subjects to maintain information in memory while solving mental problems. This conceptualization of WMC follows Baddeley and Hitch's (1974) working memory model that suggests that working memory involves information storage in the face of distraction by simultaneous cognitive processing demands.

One common type of WMC measure includes *complex span tasks*. In these tasks, participants perform simple cognitive tasks (e.g., reading, calculating, counting, etc.) while remembering information that is presented in-between the tasks for later recall (e.g., letters, digits, words, etc.). Complex span tasks come in different forms including reading span tasks (Daneman & Carpenter, 1980), operation span tasks (Turner & Engle, 1989), and counting span tasks (Case, Kurland, & Goldberg, 1982). In reading span tasks participants read a series of sentences aloud and simultaneously remember items such as letters or digits that are presented after each sentence. Participants are then asked to recall target items in correct serial order. Other span tasks work similarly. In operation span tasks, participants solve mathematical problems, while in counting span tasks they count objects of a specific shape and color. These tasks place minimal language demands on the test taker and are therefore not susceptible to language-induced subgroup differences. This is also true for a number of other complex span tasks such as symmetry span (Kane et al., 2004) and rotation span tasks (Shah & Miyake, 1996).

Another category of WMC measures are *n-back* tasks (Kirchner, 1958) that require both information storage and updating in working memory. Similar to complex span tasks, the n-back task involves the sequential presentation of a list of target items to be remembered (e.g., letters or words.). In contrast to complex span tasks, the list is not interrupted by cognitive processing tasks and instead of remembering the entire list participants are asked to recall the target item that was presented one to three trials back. More precisely, participants view target items presented in rapid sequence and have to identify which item replicates the one shown in the immediately preceding presentation (one-back task), the one shown two presentations ago (two-back task), or the one shown three presentations ago (three-back task).

Visual array comparison tasks (Luck & Vogel, 1997) represent a third category of WMC measure. In these tasks an array with geometric figures of different colors and shapes (e.g., circles, squares, and triangles) are briefly presented followed by a second array that is either similar or different from the first one. The difference between the first (sample) array and the second (test) array is modest. Participants are presented with a series of sample-test array combinations and have to judge for each trial whether the two arrays are similar or not. The difficulty of the tasks, and thus the amount of information that needs to be maintained in working memory, can be varied in terms of the number of presented geometric figures, their spatial orientation, and colors. In this task, as in all WMC tasks, better performance indicates higher WMC.

Working memory tests could aid selection decisions for occupations where short term memorization and visual comparison tasks are common. For example, wait staff in upscale restaurants must memorize menu items and specials, dialogue with customers and check on other tables, while remembering customer orders until they can be submitted ("Occupational Outlook Handbook," 2014). In occupations with working memory requirements such as these, WMC measures should be predictive of job performance among applicants. The reader should notice that each of these measures could be readily adopted for I/O and HR research in the lab and in the field. By adopting these measures in conjunction with traditional measures, researchers could quickly map these new measures onto existing results while also building a bridge to existing findings from neuroscience. At the same time researchers could investigate the relationship between these measures and actual workplace outcomes such as job performance. We believe that ultimately, this could lead to the development of simple measures that are ecologically valid, easy to administer, and predictive.

4.2. Measures of specific executive functions

The tasks described above provide general measures of WMC. However, other conceptualizations of intelligence might choose to look at more specific underlying cognitive processes. In this section, we will describe tasks that can be used to measure specific aspects of executive function. As discussed earlier, executive functions are processes that govern and regulate actions and thoughts and enable goal-directed behavior and novel problem solving (e.g. Rabbitt, 1997). Once again, neuroscience findings have connected executive function to meaningful outcomes and provide a biological basis for observed individual differences and changes over time (e.g., Kane & Engle, 2002; Koechlin & Summerfield, 2007; MacPherson, Phillips, & Della Sala, 2002). Following Miyake et al. (2000), we distinguish between three executive functions: mental set shifting, information updating, and inhibition of prepotent responses. These executive functions have either been related directly to intelligence or to the ability to apply intelligence in complex environments (Dempster, 1991; Salthouse, Fristoe, McGuthry, & Hambrick, 1998; Salthouse et al., 2003).

The ability to shift back and forth between tasks and mental sets can be measured by the simple *plus–minus* task (Spector & Biederman, 1976) in which participants are presented with three lists of digits. The task for the first list is to add 3 to each number on the list and write down the result, while the task for the second list is to subtract 3 from each number. The task for the third list involves mental set shifting between addition and subtraction operations. The completion times of the first and second lists are averaged and compared to the completion time of the third list to measure the ability to shift quickly between two opposing mental tasks. Similar tasks that can be used to measure mental set shifting ability include, for example, the *number–letter* task (Rogers & Monsell, 1995) and the *local–global* task (Navon, 1977).

Employees in managerial roles must juggle and perform a variety of tasks efficiently. They must quickly shift between these tasks as situations arise as well as monitor and provide guidance and direction to other employees on a frequent basis. As such, measures of the executive function of mental set shifting offer alternative ways to measure the ability to employees to shift back and forth between different types of tasks. Therefore, they could be used to identify candidates for advancement to managerial roles that could supplement the current reliance on job performance in individual contributor roles.

The executive function of information updating requires the ability to process incoming stimuli and update information held in working memory by replacing old information with more relevant new information. It can be measured by the *letter memory* task (Morris & Jones, 1990). The task is similar to the *n-back* task (which is also a measure of information updating ability), but in the letter memory task participants are also shown an ongoing list of to-be-remembered items, in this case letters. The participants are asked to follow the running letter series of unpredictable length and rehearse out loud the last three letters whenever the list changes. At one point the list ends abruptly and participants have to recall the final three letters of the list. The task is repeated several times and the overall proportion of letters recalled correctly provides a measure of the ability to update information held in working memory. Another similar measure of information updating ability includes the *keep track* task (Yntema, 1963) Occupations in which these measures may predict performance include emergency medical technicians and paramedics, where responding to calls requires simultaneously assessing readings from medical equipment, processing patients' observable and reported symptoms, and coordinating with team members O*NET Online (2013).

Finally, the ability for deliberate, controlled inhibition of inappropriate but dominant prepotent response tendencies can be measured by the *Stroop* task (Stroop, 1935). This well established task has become a mainstay for neuroscientific research into inhibition (MacLeod, 1991). In this task participants are presented with two lists of color words (e.g., green, blue, red etc.). In one list the color words are printed in the corresponding color (i.e., the word blue is printed in blue, the word red is printed in red etc.) while in the second list the color words are printed in a conflicting color (e.g., the word blue is printed in red, the word red is printed in green). The task requires participants to name the color of the ink in which the words are printed as quickly and accurately as possible. Participants typically find the task more difficult when presented with color words printed in a conflicting color (second list) because the prepotent response tendency is to read the words. However, by engaging effortful cognitive control it is possible to inhibit this default response tendency and instead name the color of the ink in which the word is printed. The difference in time needed for the first and second list is referred to as the Stroop effect and provides a measure of the ability to inhibit prepotent responses (MacLeod, 1991). Measures such as the Stroop task could be useful for occupations in which self-control, specifically inhibition, is critical to job performance. For example, customer service employees interact with angry customers who often do not behave in a socially acceptable manner O*NET Online (2013)). Natural responses to customer behaviors that must be suppressed may include frustration or anger.

As an extension of the aforementioned individual measures of WMC and executive functions, Higgins et al. (2007) developed a composite measure they termed dorsolateral prefrontal cognitive ability (D-PFCA). More precisely, they combined seven neuropsychological tasks associated with DLPFC function to examine how D-PFCA is related to psychometric intelligence as well as academic and job performance. As we outlined earlier, both working memory and executive functions are associated with DLPFC function. Thus, while Higgins et al. used different tasks than those described above, all these measures tap into the same underlying construct of prefrontal cognitive processes and share a common DLPFC foundation. Higgins and colleagues found that D-PFCA was significantly related to IQ and Scholastic Aptitude Test scores, but predicted academic performance over and above these two general measures of intelligence. They also found that D-PFCA predicted performance on cognitively loaded, managerial tasks as well as general mental ability. These findings demonstrate the potential value of neuroscience inspired measures of cognitive ability as viable predictors of task performance in I/O and HR contexts.

4.3. Measures of fluid intelligence

While the above measures assess specific executive functions, general measures of fluid intelligence, such as the *Raven Advanced Progressive Matrices* (Raven, Raven, & Court, 1998, Set II), provide tests of overall executive functioning and applied intelligence. Such problem solving and reasoning abilities would be important in many occupations, such as computer network support, where a substantial portion of the work requires diagnosing and solving novel problems O*NET Online (2013). Measures of fluid intelligence are becoming more common in I/O and HR research (e.g., Drasgow, 2003; Higgins et al., 2007). These studies demonstrate the utility of these types of measures for workplace research. We encourage scholars to accelerate this trend and at the same time consider and integrate the neuroscience findings and theories related to these measures.

5. Other areas where neuroscience could inform our thinking on intelligence at work

The vastness of the literature on intelligence and job performance includes a multitude of empirical studies investigating factors that moderate or mediate intelligence. Ones et al. (2010) list a number of moderators that intelligence research has supported, not supported, or not yet addressed. This literature typically categorizes predictors into cognitive and noncognitive variables and is largely dominated by the psychometric approach to general intelligence (Goldstein et al., 2009). Neuroscience research affords an interesting extension to this traditional approach by suggesting specific mechanisms for how individual, situational, and social factors affect how intelligence is realized in the workplace. Below, we highlight a few areas where we believe this new perspective might push I/O and HR research and practice in exciting and productive new directions. We focus on situational factors that affect the realization of intelligence because they present immediate opportunities for practical application. We emphasize that our purpose here is to provide a brief introduction to each factor rather than a thorough treatment.

5.1. Multitasking

Multitasking refers to the concurrent performance of multiple work tasks that is almost ubiquitous in today's workplaces. Research has shown a strong relationship between WMC and multitasking (e.g. Bühner, König, Pick, & Krumm, 2006; Colom, Martínez-Molina, Shih, & Santacreu, 2010; Hambrick, Oswald, Darowski, Rench, & Brou, 2010). As we have outlined previously, working memory is essential to fluid intelligence and executive functions that are commonly associated with multitasking such as attention, reasoning, decision making, and task switching. We have also shown that WMC represents a limited cognitive resource that shows significant individual differences. This implies that only a limited number of higher-order cognitive processes can run in parallel as multiple processing demands quickly deplete available working memory resources. This also implies that the greater a person's WMC, the more that cognitive processes can be performed simultaneously.

Two conclusions that follow from this analysis are that (1) multitasking taps WMC and leaves fewer cognitive resources for other tasks and (2) people with higher WMC should demonstrate better multitasking ability. The first point has important implications for the distinction between intelligence capacity and realized intelligence. The strong relationship between WMC and fluid intelligence implies that factors negatively affecting WMC will have a negative effect on the level of realized intelligence. Multitasking depletes working memory resources and is therefore likely to result in a reduced level of situationally realized intelligence and task performance. The second point has important implications for selection decisions. People with higher WMC have more cognitive resources available for multitasking, allowing them to perform multitasking at a higher speed and with fewer errors (Bühner et al., 2006). While intelligence and WMC are both related to multitasking when considered independently, intelligence does not predict multitasking once its correlation with WMC is controlled for (Colom et al., 2010). This implies a mediating role of WMC in the intelligence–multitasking relationship. In jobs where multitasking is a large component of successful performance, selecting applicants on the basis of general intelligence may therefore not be particularly effective. WMC and fluid intelligence measures are likely to be better predictors of performance in these job settings (Lee et al., 2006).

5.2. Job stress

Stress is another factor that has consistently been shown to impair working memory and fluid intelligence. Baddeley and Hitch (1974) first pointed out that working memory involves information storage in the face of distraction. A higher level of distraction should reduce the amount of information that can be maintained in working memory. Environmental and interpersonal stressors provide a common source of mental distraction because they induce superfluous thoughts that compete for cognitive resources. High stress has accordingly been shown to have a negative effect on realized WMC and fluid intelligence (Blair, 2006; Klein & Boals, 2001).

Job stress results from high job demands including heavy work load, time pressure, and conflicting demands—that is, high levels of performance pressure (e.g. Karasek, 1979). Recent research has revealed a surprising relationship between WMC and performance pressure. In a study involving mathematical problem solving, Beilock and Carr (2005) found that individuals high in WMC outperformed individuals low in WMC. However, under increased performance pressure individuals higher in WMC suffered greater performance decrements, while the performance of low WMC individuals was largely unaffected. The effect was so strong that the performance differences between high and low WMC individuals were eliminated. The authors suggested that high WMC individuals rely more heavily on WMC during problem solving. Indeed, research has shown that people with lower cognitive processing capacities tend to rely more on intuition and simplifying heuristics when solving problems (e.g., Hastie & Dawes, 2001).

These findings have important implications for our understanding of the relationship between intelligence capacity and realized intelligence. Most importantly, individuals high in WMC and thus fluid intelligence capacity are particularly prone to suffer performance decrements in high-pressure situations. For these individuals, the difference between intelligence capacity and realized intelligence will be particularly high in situations with high levels of performance pressure or other job stress. In fact, when working under high levels of job stress and pressure high intelligence capacity individuals are not likely to outperform their lower intelligence colleagues. On the other hand, this also means that some individuals with high intelligence capacity may not perform well in high-pressure selection tests. Beilock and Carr (2005, p. 104) argued along these lines “that the individuals most likely to fail under pressure are those who, in the absence of pressure, have the highest capacity for success.” This has important implications given the current prevalence of high-stakes selection tests in academics and organizations. One could conclude that those selection tests could be counter-productive in situations where high stress is a feature of the job description.

5.3. Interaction between emotion and cognition

Successful job performance requires more than just fulfilling the cognitive demands of job tasks; incumbents generally must also deal with the emotional demands of their role in order to perform well. In the past, it was largely assumed that emotions and cognition were distinct processes that tended to act in opposition. Along these lines, strong emotions can limit or even preclude the conscious application of cognitive resources (Loewenstein, 1996). At the same time, the literature on emotional regulation demonstrates that cognitive resources can be employed to consciously manage emotional responses (Gross, 1998). Recently, findings from neuroscience suggest that the lines between emotion and cognition are not as distinct as our theories imply and that they are much more integrated within the brain (Pessoa, 2008). We believe that this topic will evolve rapidly and has important implications for the realization of intelligence capacity in the workplace. However, for the purposes of the current article, most of the research to date has investigated cognitive control over emotion, and the findings provide a number of implications for situational applications of intelligence.

Generally speaking, emotional episodes redirect attentional focus from the task at hand to circumstances surrounding the affective experience. This happens due to four resource-demanding aspects of affective experiences: appraisal, rumination, arousal, and cognitive requirements (Sonnemans & Frijda, 1994). Employees with a higher level of intelligence ostensibly engage in conscious appraisal, rumination, and regulation to a greater extent than lower intelligence employees. However, this may leave these individuals with fewer mental resources to devote to work tasks. In this way, the interaction between emotion and cognition at work may affect realized intelligence on the job, such as when a customer service employee must respond appropriately to abuse from an angry customer.

Research findings to date are mixed and suggest a nuanced relationship between emotion and cognition interactions with respect to performance. One perspective is that self-regulation taps cognitive resources. Higher order cognition typically requires executive functioning in the brain and thus depletes cognitive resources within individuals (Crinella & Yu, 1999). This depletion of cognitive resources from self-regulatory efforts reduces the amount of effort and persistence directed towards other tasks (e.g. Muraven, Tice, & Baumeister, 1998). To the extent that some people experience a high variety and intensity of emotions, they will deplete their self-regulatory resources and exhibit lower performance on subsequent job tasks. Shamosh and Gray (2007) conducted a study of the effects of emotion regulation on subsequent task performance. Results revealed that people high in fluid intelligence showed more impairment on cognitive tasks than people lower in fluid intelligence while performing emotional regulation. The emotional regulation requirements of the work context and lack of emotional stability can impair work performance, especially in more intelligent employees.

An alternative perspective is that increased emotional regulation is associated with higher subsequent performance. Keith and Frese (2005) found that emotion control and metacognition mediated the effect of training on performance so that individuals exhibiting more control of their emotions tended to exhibit higher performance. It bears noting that current evidence fails to support the notion that emotional intelligence, as measured by the Mayer–Salovey–Caruso Emotional Intelligence Test (MSCEIT), provides incremental predictive validity over and above standard measures of intelligence for outcomes like prosocial behavior, leadership, and organizational behavior (Brody, 2004). In sum, findings from the current literature about the interaction between emotion and cognition at work are mixed and this is an area where the application of neuroscientific methods could help to resolve these issues.

To date, neuroscientific methods have primarily been employed to investigate the brain systems responsible for emotional response and subsequent regulation (e.g. Banks, Eddy, Angstadt, Nathan, & Phan, 2007; Hamann & Canli, 2004; Phan, Wager, Taylor, & Liberzon, 2002). In the future, neuroscientific methods could be employed to trace the temporal dynamics and interactions between emotions, self-regulation, and cognitive resources. Systematic research that employs traditional- and neuroscientific methods would be able to investigate the extent to which emotional regulation at work taxes working memory and other cognitive resources and leads to lower realized intelligence (Hofmann, Schmeichel, Friese, & Baddeley, 2011). This integrated approach represents the most promising means to more definitively answer the questions raised above and provide practical advice for dealing with workplace emotions without draining cognitive resources.

6. Discussion

The advent of organizational neuroscience provides a fresh perspective on intelligence that can shed new light on the role of intelligence in the workplace. Neuroscience-based intelligence research has been relatively underutilized in organizational research but provides a number of opportunities for advancing I/O and HR theory and practice. We have highlighted a few of these opportunities here. In addition, the findings from neuroscience provide a level of analysis and specificity in describing cognitive processes that can help refocus intelligence research in the workplace. We believe that investigating individual differences and contextual variables that influence realized intelligence and performance in organizational settings should be a prominent future goal. Similar to the idea of maximal and typical performance (DuBois, Sackett, Zedeck, & Fogli, 1993), individuals can vary in intelligence such that a person who scores high on an traditional intelligence tests (demonstrates high intelligence capacity) might demonstrate low realized intelligence due to contextual variables. The converse is also true, and potentially more interesting for practice. As we have shown, neuroscience can provide new perspectives, methods, and measures that can complement traditional approaches to these questions.

The organizational neuroscience perspective of intelligence in the workplace provides a number of exciting implications. First, organizational neuroscience makes an important distinction between intelligence capacity and realized intelligence. Due to individual and situational moderators, the high general intelligence capacity of individuals may not be fully realized (e.g., in chronically high stress work environments). Currently, the I/O and HR literature generally assumes that individuals who score high on intelligence assessments will act intelligently on the job and will perform better than other applicants. This assumption has served I/O and HR reasonably well (Ones et al., 2010). Organizational neuroscience provides a potentially fruitful avenue to move forward on both accounts and advance research and practice.

Second, an organizational neuroscience perspective shifts the focus from debating the structure of intelligence assessments, to investigating variables that are potentially important to realized intelligence in organizational settings. Thus far, I/O and HR as a field has thoroughly researched general intelligence across multiple contexts as a predictor of job performance and other work behaviors. The intelligence literature in I/O and HR generally measures intelligence capacity of individuals based on assessments such as the Wonderlic Personnel Test. We contend that it may be more valuable to organizations to employ specific intelligence and executive function measures that reflect the job design of the position in question rather than assessing general intelligence capacity. Organizational neuroscience prompts a nuanced view of intelligence in which specific interactions between person, environment, and job tasks contribute to realized intelligence.

7. Future directions

An initial step to improve the prediction of realized intelligence is to add a brain level to job analysis by assessing the level of intelligence it takes to complete job-specific tasks. In addition to recording and categorizing job responsibilities, KSAOs, and tasks, we can use organizational neuroscience to assess the dimension and level of a specific mental capacity or executive function required to complete particular tasks. For example, it is conceivable to determine the WMC requirements associated with documenting information while talking on the phone with customers. From there, employers could select applicants who exhibit WMC at or above the determined, task-specific threshold. Going further, this threshold may need to be adjusted for situational factors such as anticipated job stress and emotional regulation demands.

After determining the predictive validity of alternative measures of WMC and executive functions, researchers could then investigate the incremental validity of these measures beyond traditional measures of intelligence. Investigating the relations between specific intelligence and executive function measures and job performance will be valuable in the selection context. With more specific information, practitioners can increase parsimony in selection systems by allowing them to tailor intelligence measures to specific job tasks and conditions. For example, for positions in organizations and industries that require novel problem solving, a greater emphasis should be placed on executive function measures.

As our measures of intelligence capacity of individuals continue to mature, the next step will be to develop the ability to predict and improve realized intelligence. Like other areas of I/O and HR, realized intelligence is a function of the person and environment necessitating simultaneous consideration of moderators such as multitasking, and individual difference variables such as mental health. A neuroscience perspective will be advantageous for predicting the effects that different moderators can have on realized intelligence during job-specific tasks and conditions. Similarly, neuroscience will certainly impact organizational life in ways we cannot currently foresee. For example, neuropharmacology may soon produce cognitive enhancement drugs that are readily available to the general public and be used to temporarily raise individual intelligence capacity (Greely et al., 2008).

As with any approach there are challenges to overcome and organizational neuroscience is no exception. Neuroscience intelligence research faces a number of technological and methodological challenges in addition to difficulties associated with interdisciplinary research including communication, measurement, and theory integration. Furthermore, basic neuroscientific research can be expensive. Lastly, a neuroscience perspective will force us to deal with new ethical considerations and dilemmas. Although there is certainly a cost to conducting organizational neuroscience research, we believe the potential to advance I/O and HR research and practice far outweighs the costs.

8. Conclusions

The organizational neuroscience perspective of intelligence in the workplace provides a number of opportunities to advance research and practice. Here, we have briefly introduced the reader to a number of these opportunities. First, neuroscience forces us to refine and reconceptualize our definition of intelligence to include intelligence capacity versus realized intelligence and specific facets of intelligence. Second, it suggests we add new measures to our tool kit. Third, it recommends a number of individual and situational moderators that need to be explored further in order to understand the role of intelligence in work performance and behavior. Overall this perspective has the potential to move the field toward a new level of specificity in which the consideration of interactions between individual differences and contextual variables improve the predictive validity of one of HR and I/O's oldest and strongest predictors of job performance–intelligence.

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