Running head: THE DETECTION OF PFC DEVELOPMENT

The Detection of Prefrontal Cortex Development into Early Adulthood

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Abstract

Based on neuroimaging evidence that the development and maturation of the prefrontal cortex (PFC) continues beyond adolescence, and is completed only in early adulthood, this study was undertaken to determine if these functional differences in the human brain are evident in commonly used behavioral measures of PFC functioning. To this end, two age groups were tested. The 18-year-old participants represented the continuation of brain development, and the 22-25-year-old participants represented the completion, or near completion, of brain development. In support of the central hypothesis, the older group outperformed the younger group on PFC measures. The study also analyzed age differences in terms of tasks predominantly tapping the dorsolateral PFC (DLPFC) and the ventromedial PFC (VMPFC). The hypothesis of larger age differences for the DLPFC, due to its later maturation, was not supported. A final purpose of this study was to examine if life stress could be a mediating factor in the cognitive maturation of the PFC. Results revealed that negative stress scores were the best predictors of PFC functioning, but that there was no strong systematic relationship between life stress and PFC functioning in the age groups tested.

The Detection of Prefrontal Cortex Development into Early Adulthood

Neuroimaging evidence has revealed that the human brain does not complete development at puberty. Structurally, the human brain continues to grow into late adolescence; functionally, it appears to mature into early adulthood (Bechara, 2004; Casey, Giedd, & Thomas, 2000; Dekaban & Sadowsky, 1978; DeLuca, Wood, & Andersen, 2003; Fuster, 2002; Fuster & Alexander, 1971; Giedd et al., 1996; 1999; Giedd, 2004; Gogtay et al., 2004; Luna & Sweeney, 2001; Huttenlocker, 1979, 1990; Nagy, Westerberg, & Klingberg, 2004; Paus, 2005; Romine & Reynolds, 2005; Sowell et al., 1999, Sowell, Tessner, Thompson, & Toga, 2002) and perhaps even beyond (Yakovlev & Lecours, 1967). Adolescence is characterized as the phase between childhood and adulthood. While it is difficult to assign an exact time period for the term "adolescence", the theory most commonly accepted is that adolescence is the period that encompasses puberty and the second decade in the human life span, when the individual moves from a state of dependency to independency, owing to physical and cognitive changes (Bornstein & Lamb, 1999; see also Luciana, Conklin, Hooper & Yarger, 2005; Newman & Newman, 1991; Spear, 2000). Hence, taking into account the different theories regarding the time period of adolescence, for the purpose of this study, I will refer to adolescence as the time period between the ages of eleven years and nineteen years.

The PFC in particular has been a region of interest in neurodevelopmental studies as it has been implicated in higher cognitive functions (Holyoak & Kroger, 1995; Luciana et al., 2005; Luria, 1966; Stuss & Levine, 2002). Several studies refer to the third decade of life as the period when the PFC attains maturation or optimal achievement of these functions (Case, 1992; Casey et al., 2000; De Luca et al., 2003; Fuster, 2002; Huttenlocher, 1979, 1990; Nagy et al., 2004; Sowell et al., 2002; Yakovlev & Lecours, 1967). An underdeveloped PFC can result in inefficient life skills via cognitive and social immaturity as seen in deficits in decision making and planning, incompetence in reasoning, evaluating risk and reward, and making judgments under conditions of uncertainty, working memory, allocation of attention resources, inhibitory control, and impulsive behavior. All of these are functions in which the PFC plays a critical role (Case; Casey et al ; Diamond & Goldman, 1989; Duncan, 1986; Fuster, 1989, 2002; Goldman-Rakic, 1990; Holyoak & Kroger ; Luciana & Nelson, 1998; Luria, 1966; Miller & Cohen, 2001; Miyake, Friedman, Emerson, Wisk, & Howerter, 2000; Rainer & Ranganath, 2001; Sowell et al., 1999; Stuss, 1992; Stuss & Levine, 2002).

The purpose of the present study was to determine if this functional development in the PFC through adolescence and into early adulthood is evident in commonly used behavioral measures of PFC functioning. To this end, I compared two age groups, 18- and 22-25-year-olds, on PFC tasks. This age period was chosen as it reflects the continuation and completion, or near completion, of brain development. I hypothesized that the older group would outperform the younger group on PFC measures overall. In addition, there is the possibility that two distinct regions of the PFC, the dorsolateral PFC (DLPFC) and the ventromedial PFC (VMPFC) (see Lamar & Resnik, 2004; MacPherson, Phillips, & Della Sala, 2002; Stuss & Levine, 2002; Wood & Grafman, 2003), may show different developmental trajectories. Research suggesting a later development of the DLPFC compared to the VMPFC (Diamond, 2001; Diamond & Goldman-Rakic, 1989; Giedd, 2004; Happaney, Zelazo, & Stuss, 2004; Huttenlocher, 1979; MacPherson et al., 2002) supported the second hypothesis of study, that there would be larger age effects in the DLPFC tasks compared to the VMPFC tasks.

Prior research has established the crucial role the PFC plays in executive functions, which are essential in many aspects of everyday life. Although brain development is largely directed by our inherent genetic code, one environmental factor identified as impacting optimal brain development is life stress (Bremner, 1999; Bremner & Narayan, 1988). Stress can be defined as anything that seriously disturbs the body's psychological or physiological homeostasis (Selye, 1956), and has an effect on cognitive functioning (Arnsten 1998 a, 1998 b; Arnsten & Shansky, 2004; Kim & Yoon, 1998; Selye, 1956). Human and animal studies have shown the PFC to be sensitive to stress and this is significantly so during the transitional period between adolescence and adulthood (Arnsten & Shansky; Bar-Tal, Raviv, & Spitzer, 1999; Bremner; Dahl, 2004; Darke, 1988; Diamond, 2001; Galotti, 2001; Gerrittis et al., 2003; Teicher et al., 2003; Spear, 2000a, 2000b) when "important life decisions" are also being made (Galotti, 2001, p. 275). Hence, the final hypothesis of this study was that higher life stress would be associated with lower PFC performance. This study proceeded in light of past findings from post mortem and neuroimaging studies as well as behavioral measures that have established the developmental trajectory of the PFC and its importance in performing executive functions.

Structure and Functions of the Prefrontal Cortex

The PFC occupies a third of the anterior part of the frontal lobes (Fuster, 1989, 2002), and functions to support higher-order thought and behavior (Fuster, 2002; Wood & Grafman, 2003). The PFC has numerous connections to and from other areas of the brain. Its position enables connections with the sensory, motor, limbic and other cortical and subcortical areas, giving it an integrative ability (Goldman-Rakic, 1987; Miller & Cohen, 2001). Throughout development in childhood and adolescence, increases in the complexity of PFC neuronal networks (Anderson, Anderson, Northam, Jacobs, & Catropa, 2001; Chi, Dooling, & Giles, 1977; Diamond & Goldman-Rakic, 1989; Huttenlocher, 1990; Nagy et al., 2004) allow for the emergence of higher cognitive functions (Anderson et al., 2001; Fuster, 2002; Luna et al., 2000;

Luna & Sweeney, 2004; Nagy et al).

The development of the PFC is related to the ability to perform executive functions (Casey et al., 2000; Case, 1992; DeLuca et al., 2003; Diamond & Goldman-Rakic, 1989; Duncan, 1986; Fuster, 1989, 2002; Goldman-Rakic, 1990; Luciana & Nelson, 1998; Luria, 1966; Miller & Cohen, 2001; Miyake et al., 2000; Shallice & Burgess,1991; Sowell, Delis, Stiles, Jernigan, & Stuss, 1992), which include multitasking abilities such as reasoning, planning, decision making, attention, and impulse control. From an adaptationist standpoint, these are functions that help an individual in achieving goals and dealing effectively with novel situations (Bechara, Damasio, Damasio, & Anderson, 1994; Case; Dubois et al., 1995; Duncan ; Fuster; Goldman-Rakic, 1992; Luria ; Holyoak & Kroger, 1995; Miller & Cohen ; Petrides & Milner, 1982). However, as revealed from research findings, the PFC is the last to develop and reach maturity (Casey et al ; Changeaux & Danchin 1976; Duncan ; Fuster 2002; Giedd et al., 1999; Diamond & Goldman-Rakic, 1989; Luria ; Stuss, 1992; Yakovlev & Lecours, 1967).

Dorsolateral and Ventromedial PFC

The PFC is a heterogeneous region (Fuster, 2002; Happaney et al., 2004; Hartikainen & Knight, 2003; Miller & Cohen, 2001, Rainer & Ranganath, 2001; Romine & Reynolds, 2004, Wood & Grafman, 2003) which is subdivided into several areas, each playing its own part in the executive functions (Crone & van der Molen, 2004; Goldman-Rakic, 1990; Hartikainen & Knight, 2003; Stuss & Levine, 2002, Rainer & Ranganath). Two distinct subdivisions of the PFC are the DLPFC and the VMPFC (MacPherson et al., 2002; Crone & van der Molen, 2004; Fuster, 2002; Krawzyk, 2002; Stuss & Levine; Wood & Grafman). These regions have been largely implicated in executive processes and though they often work in unity, they remain functionally distinct. This has been seen through a double dissociation of PFC structures. Individuals with damage to VMPFC show poor performance on tasks that tap cognitive functions associated with this region and no impairment on performance on tasks that utilize the DLPFC functions, whereas individuals with DLPFC damage show the opposite pattern (Bechara, 2004).

The upper and side regions of the frontal lobe are referred to as the DLPFC, whereas the VMPFC is located in the innermost regions extending towards the median line and the ventral surface of the frontal lobes (Damasio, 1994; Krawzyk, 2002). The DLPFC is said to have evolved from the motor region and it develops and reaches maturity later than the VMPFC (Diamond, 2001; Fuster, 2002; Goldman-Rakic, 1987; Kwon, Reiss & Menon, 2002; Rubia et al., 2001), even continuing its maturation into adulthood (Diamond ; Giedd, 1990). A debate currently exists as to whether the development of the VMPFC is on a similar developmental timeline as that of the DLPFC (Hooper, Luciana, Conklin, & Yarger, 2004; Crone & van der Molen, 2004). However, several studies support the idea that the DLPFC is the later brain region to mature (Fuster; Giedd, 1996; Gogtay et al., 2004; Paus, 2005).

The DLPFC and the VMPFC can be defined more specifically in terms of their functions as well (Bechara, Damasio, Tranel, & Andersen, 1998; Holyoak & Kroger, 1995; MacPherson et al., 2002; Stuss & Levine, 2002). The VMPFC is thought to underlie social and impulse control (Bechara, Damasio, & Damasio, 2000; Krawzyk, 2000; Rolls, 2000), and according to Damasio, is “critical to normal decision-making” (1994, p. 33). The location of the VMPFC allows close connections with the limbic system. Hence, the VMPFC has been implicated both in emotional processing (Bechara, 2004; Krawzyk) as well as in higher-order sensory processing (Crone & van der Molen, 2004; Hooper et al., 2004; Rogers et al., 1999; Stuss & Levine ; Wood & Grafman, 2003). Studies show that while damage to the VMPFC does not impair sensory and motor functions, it affects decision making (Bechara et al., 1998). Significant decision-making deficits are seen both in social situations, specifically those which necessitate complex social interactions (Gallagher & Frith, 2003; Saver & Damasio, 1991; Shamay-Tsoory ,Tomer, Beger, Goldsher, & Aharon-Peretz, 2005; Shamay-Tsoory, Tomer, Beger, & Aharon-Peretz, 2003; Stone, Baron-Cohen, & Knight, 1998), as well as in evaluating risk and reward in terms of future outcomes (Bechara et al., 1994; Holyoak & Kroger, 1995; O'Doherty, Kringlebach, Rolls, Hornak, & Andrews, 2001).

The DLPFC has close connections with other association areas, most notably the sensory and motor areas (MacPherson et al., 2002). Hence, the DLPFC subserves motor control, performance monitoring, and higher-order sensory processing (Goldman-Rakic, 1990; Fuster, 1989, 1996, 2000; Rogers et al., 1999; Miller & Cohen, 2001), and is implicated in goal-directed behavior and executive functions, particularly in the areas of attention and working memory (Cohen et al., 1997; D'Esposito et al., 2005; Fuster, 2002; Holyoak & Kroger, 1995; Krawzyk, 2000; Luciana et al., 2005; MacPherson et al., 2002; Nagy et al., 2004; Stuss & Levine, 1992). Findings from neuroimaging studies have implicated the DLPFC in tasks that demand logical reasoning and the VMPFC in tasks requiring functions like guessing or intuition (Elliott, Rees, & Dolan, 1999; Goel & Dolan, 2003), and decision-making (Damasio, 1994).

To enable the high-level functions of executive performance, the PFC needs a sophisticated system for the integration and organization of goal-directed behavior, internal states, and past knowledge (Fuster, 2002; Luciana et al., 2005; Miller & Cohen, 2001). Hence, the PFC must be able to select appropriate stimuli and responses based on a multitude of competing and complex stimuli; while at the same time must eliminate distracting choices and suppress inappropriate behavior. The PFC achieves this function through the integrative processes of working memory, attention allocation, and inhibitory control (Rakic, 1987). Studies show that the DLPFC and the VMPFC are areas critically involved in these processes (D'Esposito et al., 2000; Fuster; Krawzyk, 2000; MacPherson et al., 2002; Meyer et al. 1996; Stuss & Levine, 1992).

Researchers have identified the most important cognitive processes enabling goal-directed behavior as including "working memory and the voluntary suppression of context-inappropriate responses" (Luna & Sweeney, 2001, p. 443; Wood & Grafman, 2003). Working memory (WM) is the process that enables holding and manipulating information for a short period of time (Baddeley, 1986). This function enables our day-to-day cognitive skills and the performance of executive functions (Fuster, 2002; Smith & Jonides, 1998a, 1999b). In Baddeley's working memory model, the central executive is the mechanism that oversees the two slave systems: the phonological loop, used for language processing general verbal tasks, and the visuo-spatial sketchpad, used for visual and spatial processing. This model describes the processes of coding, maintaining, storing, and manipulating mental representations; however, Baddeley did not establish a neural basis for these functions. This has been made possible with the technological advances in the neuroimaging field.

Taking into account these neuroimaging findings together with lesion studies, researchers have suggested that DLPFC subserves working memory (Cohen et al., 1997; D'Esposito et al., Jonides et al., 1997; Petrides, 1993, see also Goldman-Rakic, 1987, 1992; Nagy et al., 2004). Both human as well as non-human primate studies (Fuster & Alexander, 1971; Funahashi, Bruce, & Goldman-Rakic, 1989; Goldman-Rakic, 1992, 1996) have confirmed the role of the DLPFC in working memory. In non-human primate studies, DLPFC damage has been shown to lead to an absence of goal-directed behavior and deficits on delayed-matching-to-sample tasks (Diamond, Funahashi, Bruce, & Goldman-Rakic, 1989; Fuster & Alexander, 1971; Goldman-Rakic; Rainer

& Ranganath, 2002). In studies of brain functioning in monkeys, activation in DLPFC neurons was noticed during a period of delay during which the monkey maintained information about a visual stimulus across a short delay (Fuster, 2001; Goldman-Rakic, 1996).

In the ensuing paragraphs I will focus on two important functions, which according to Bechara et al, are “distinct operations of the prefrontal cortex” (2000, p. 301). These operations are working memory, a function shown to be subserved by the DLPFC; and that of decision making, a function shown to be subserved by the VMPFC (Bechara et al., 1998).

DLPFC and Working Memory.

The DLPFC shows high activation during the short-term storage, maintenance and manipulation of information (Cohen et al., 1994; Diamond & Goldman-Rakic, 1989; Krawzyk, 2002; Smith & Jonides, 1998, 1999). The role of the DLPFC in the central executive system of working memory (Cohen et al ; Goldman- Rakic, 1996) was explored in an fMRI study (D’Esposito et al., 1995) by observing brain activation during single- and dual-task performance of two non-working memory tasks (i.e., semantic judgment and spatial rotation). Whereas individual performance of each task showed non-PFC activation, the dual-task condition showed significant increased activation seen in the DLPFC. Other studies have supported this conclusion regarding the role of DLPFC in central executive functioning (Casey et al., 2001; Cohen et al., 1997; D’Esposito et al., 1998; Luna et al. 2000; Luna & Sweeney, 2001; Petrides, 1993; Smith & Jonides, 1999).

The relationship between the DLPFC and executive functions has also been seen in the effect of brain damage on the Self-Ordered Pointing Task (SOPT; Petrides & Milner, 1982), a spatial search task that requires the participant to continuously monitor and update information and make a selection from the responses held in WM. For each SOPT trial, participants are shown a set of the same stimuli in different orderings, and told to choose a new item each time (Petrides & Milner; MacPherson et al., 2002). The task becomes increasingly difficult as the number of items and trials increases. Due to its demands for organization, attention, planning, and strategy, the task is thought to require working memory. Petrides and Milner used the SOPT to test frontal lobe deficits on executive performance, and found that patients with frontal lobe damage showed larger deficits on executive performance compared to normal controls and to those with temporal lobe damage. Neuroimaging studies have confirmed that the SOPT predominantly taps the DLPFC (Petrides, Alivisatos, Myer & Evans, 1993; Petrides, Alivisatos, Evans, & Myer, 1993; see also MacPherson et al., 2002; Lamar & Resnik, 2004).

The DLPFC is also strongly implicated in a task involving the active maintenance and continual updating of recent information (Cohen et al., 1997), namely the *n*-back task (Dobbs & Rule, 1989; D'Esposito et al., 1995, 1998; Jonides et al., 1997; Smith & Jonides, 1999). This task involves both the storage and maintenance functions of working memory. During this task, the participant must decide whether each currently presented stimulus is identical to the one presented *n* items previously. Working memory load is manipulated by changing the level of *n*. For example, in a 3-back task, the participant has to mentally compare the current stimulus with the one that appeared 3 positions previously. Neuroimaging studies of the *n*-back task (Carpenter, Just, & Reichle, 2000; Cohen et al., 1997) have revealed progressive increases in DLPFC activation as the level of *n* increases (D'Esposito et al., 1999; Jonides et al., 1997). Other studies have also confirmed the role of DLPFC in working memory. Both the SOPT and the *n*-back task appear to provide strong behavioral measures of DLPFC functioning as evidenced in several other studies (Lamar & Resnik, 2004; MacPherson et al., 2002; Smith & Jonides, 1999), and are included in this study as DLPFC measures.

VMPFC and Decision-Making.

The VMPFC appears to plays a role in the positive and negative emotional states that guide successful performance of executive tasks (Bechara, 2004; Davidson & William, 1999; Happaney et al., 2004; Krawzyk, 2002). This hypothesis has been confirmed in neuroimaging studies (Bechara, et al. 1998; Happaney et al; Harlow, 1968; Stuss & Levine, 2002). Abilities like decision-making, social cognition, self-regulation and inhibition, risk and reward assessment, self and social awareness, and personal and social skills, are significantly impaired in individuals who have suffered VMPFC lesions, compared to healthy controls (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Bechara et al., 1994; Rolls, 2000; Saver & Damasio, 1991; Shamay-Tsoory et al., 2005). This pattern of cognitive deficits has prompted a plethora of research relating to gambling behavior, which represents these functions to the extent that gambling requires the weighing of short-term gain against long-term consequences.

Gambling tasks have been developed to measure VMPFC damage and have been used in neuroimaging studies (Rogers et al., 1999). The most common such task is the Iowa Gambling Task (IGT; Bechara et al., 1994). In the IGT, participants are given four decks of playing cards. Two decks are advantageous, yielding low profits but also low losses. The gains are steady and certain and hence profitable in the long run. The other two decks are disadvantageous, yielding high immediate gains but also high losses. Though extremely profitable in the short run, these decks have adverse long-term consequences (high immediate gain and large future loss). Hence, choosing from these decks it is ultimately risky and unprofitable. Those without VMPFC damage tend to avoid the disadvantageous decks and choose the advantageous ones, whereas individuals who have VMPFC deficits display the opposite behavior and end up with losses. Performance on this task can be generalized to real-world decision-making, which is also impaired in such individuals. They are unable to evaluate immediate and delayed reward and punishment and foresee future outcomes, an ability crucial for survival.

Decision-making, such as that evidenced in the IGT, appears to involve not only VMPFC functions related to risky decision-making, but also WM. However, WM does not appear to be dependent on decision-making ability (Crone & van der Molen, 2004). This relationship between WM and decision making was examined in a study comparing individuals with VMPFC damage to individuals with DLPFC damage, along with normal controls (Bechara et al., 1998). Participants performed the gambling task, which presumably taps the VMPFC, and varieties of delayed-match-to-sample tasks, which presumably tap the DLPFC. In the delayed-match-to-sample task, stimuli were presented for a brief period of time, followed by a distraction-filled delay to prevent rehearsal, followed by a second stimulus presentation during which participants were required to choose the current stimulus that matched one of the original set. Intact WM functioning is needed for these tasks. This study found that individuals with VMPFC damage who did not do well on the gambling task performed well on these delay tasks, indicating that working memory was not dependent on decision making. However, individuals with DLPFC deficits showed impaired working memory, resulting in poor performance on both the delayed-match-to-sample and the gambling tasks. According to Bechara, “deficits in decision-making occur independent of deficits in working memory, deficits in working memory compromise decision-making” (2004, p. 35). This one-way dissociation is relevant to the current study because the inclusion of the gambling task must be interpreted as a measure predominantly (but not selectively) tapping the VMPFC.

Several studies have also evidenced the role of ‘emotion’ in decision making (Bechara et al., 2000; Bechara, 2004; O’Doherty et al., 2001) Neuroimaging studies of emotion have revealed the role of the VMPFC along with other brain areas in learning as well as in moral and social judgment (Greene & Haidt, 2002; see also O'Doherty et al.) Bechara (2004), proposed his somatic marker hypothesis based on results from the gambling studies, suggesting that decision-making is guided by emotions. Damage to the VMPFC interferes with the normal processing of emotional or somatic signals, which in turn hampers decision-making (Bechara et al., 2000). Impaired judgment in decision-making can have detrimental consequences not just in the laboratory, but also in personal and social contexts (Saver & Damasio, 1991; Steinberg, 1996, 2004).

The VMPFC mediates social cognition and judgment (Greene & Haidt, 2002), and has been implicated in what is called the "theory of mind" (Stone et al., 1998). The "theory of mind" is the ability to infer another person's state of mind (Gallagher & Frith, 2003; Shamay-Tsoory et al., 2005; Wellman & Wooley, 1990), which enables complex social interactive skills (Stone, et al. 1998). This appears to be a function unique to humans and develops gradually from childhood through adolescence and into adulthood. It enables complex social interactive skills (Stone et al; Wellman & Wooley), and this knowledge can guide and direct goals (Gallagher & Frith).

The Faux Pas task (Stone et al., 1998) has been used to test theory of mind and false beliefs. In the task, participants read a series of short stories, some of which contain a 'faux pas' or a 'social slip' (see MacPherson et al., 2002). The faux pas stories contain a situation in which one of the characters in the story says something that is not only socially awkward or inappropriate, but which can be upsetting to another person in the story (see Stone et al). To realize that a faux pas has occurred, participants must be able to understand that the 'faux pas' or the inappropriate statement made by the person in the story, was unintentional, and at the same time, the participant must understand the hurt caused to someone else and be able empathize with that person against whom the faux pas was directed (Stone et al). Recognizing a faux pas requires understanding that there is a mistaken or false belief and empathizing with the person who is the victim of the false belief, an ability purportedly subserved by the VMPFC. Significantly greater VMPFC activation has been found in normal controls and even in individuals with DLPFC lesions when they perform this task, compared to those with VMPFC damage, who are unable to detect a faux pas has been committed (see MacPherson et al ; Stone et al.). Theory of mind ability is normally in place by the age of seven but improves over time into adolescence, when it is more likely for an individual to detect a faux pas (Stone, et al).

Researchers have learned a great deal about the functions of the DLPFC and the VMPFC through lesion and neuroimaging studies as well as through behavioral tasks. Also relevant to the current study is the developmental trajectory of these functions.

Mechanisms of Development in the PFC

“The PFC undergoes the greatest expansion in the course of both evolution and individual maturation” (Fuster, 2002, p. 373). Executive functions, though present early in life, continue to mature into early adulthood (Hooper et al., 2004; Romine & Reynolds, 2005). Most of the development of the human brain is completed prenatally and it achieves roughly 90% of its adult size by childhood (Giedd, 1996; Jernigan, Trauner, Hesselink, & Tallal, 1991). In human brain development, a pattern of posterior to anterior is followed. The regions of the brain associated with our basic, primary functions, such as the motor, visual, and auditory areas, are the earliest to mature, whereas the regions that integrate the functions of these older areas and underlie our highest mental capacities mature much later (Casey et al., 2000; Gogtay et al., 2004; Romine & Reynolds, 2005; Yakovlev & Lecours, 1967). Early studies of human brain development came from autopsy reports of brain tissues (Yakovlev & Lecours; Dekaban &

Sadowsky, 1978; Huttenlocher, 1979). Although these methods were limited, they provided a great deal of insight into brain development. Most importantly, they established an index of brain maturation by identifying two developmentally essential processes, pruning and myelination.

Toward the end of the prenatal period, the human brain has developed many more synapses than are needed, in a process called synaptogenesis. Beginning in the period after birth, we see a “survival of the fittest” paradigm, where only the synapses that are used or find another to fire with survive, whereas those that do not get eliminated (Huttenlocher, 1979, 1984, 1990). Huttenlocher (1979, 1984), found that this overproduction and subsequent elimination (i.e. pruning) of the unwanted synapses through adolescence actually strengthens the remaining neural system and refines it. This process underlies the maturation of executive functions (Giedd, 1999). Although the first two “waves” of pruning take place early in life, the third wave, occurring just before puberty, causes a decline in gray matter (Changeaux & Danchin, 1976; Huttenlocher, 1979, 1984, 1990).

While synapse creation and strategic pruning facilitate the functioning of the vast neuronal network, a process called myelination ensures the efficiency of this function. Acting like an insulator on the axons of neurons, myelin promotes an efficient and faster transmission of signals (Giedd, 1999; Hooper et al., 2004; Nagy et al., 2004), thereby enhancing cognitive abilities. Yakovlev and Lecours (1967) established the developmental trajectory of myelination by examining hundreds of brain autopsies from the fourth fetal month through the life span. Their research revealed a different developmental trajectory for different brain regions and showed development extending into the third decade of life via myelination. In particular, and of importance to the current study, a consistent pattern of earlier myelination for the sensory and motor regions than for the frontal regions was observed (see also Huttenlocher, 1979, 1990). The ongoing maturation process of frontal lobe white matter (via myelination) appears to extend well into the second decade of life, coinciding with the timing of functional brain maturation and higher order complex cognitive capacities (Giedd ; Gogtay et al., 2004; Nagy et al., 2004; Paus, 2005; Sowell et al., 1999; Sowell et al., 2001). Myelination is seen as the foundation for the gradual development and the index for functional maturation of the prefrontal regions.

The brain areas subserving our primary functions mature earlier than the evolutionarily more "recent" brain areas that integrate the workings of these areas. Additional support for the evidence from brain autopsy findings (Dekaban & Sadowsky, 1978; Huttenlocher, 1979; Yakovlev & Lecours, 1967) has been gained in an imaging study by Gogtay et al. (2004). To plot an anatomical sequence of human cortical gray matter development in healthy individuals in the age range of four to twenty-one years, Gogtay et al. obtained anatomic brain scans every 2 to 8 years. They showed that areas associated with the most complex cognitive abilities were the last to develop; in particular, the frontal area associated with executive functioning was the final area to mature, showing a continued loss of gray matter (via pruning) in the DLPFC through adolescence.

This developmental pattern of PFC maturation was also confirmed in a longitudinal neuroimaging study by Giedd et al. (1996), in which the maturation of the DLPFC was found to continue for at least a decade after puberty, into the twenties, and was the last brain region to reach maturity. Their findings establish that while the size of the brain remains relatively stable, gray matter volume increases in early stages of development, followed by a loss around puberty, again supporting the pruning theory of brain maturation. White matter volume increased throughout childhood in a linear pattern between the ages of four and eighteen years, indicating faster transmission between neurons via the process of myelination. Additional support for this conclusion comes from PET studies (Chugani, 1998) that showed an increase in overall glucose metabolism in the frontal lobes during the first decade of life, followed by a decrease during early adolescence, with adult levels reached by age 18. This finding coincides with the time course of the overproduction and pruning of synapses and shows a protracted development for the PFC compared to other sensory and motor areas (for similar neuroimaging studies, also see O'Donnell et al., 2005; Jernigan, Trauner, Hesselnik, & Tallal, 1991; Lange, Giedd, Castellanos, Halitosis, & Rapoport, 1997; Nagy et al., 2004; Paus, 2005; Pfefferbaum et al., 1994; Sowell et al., 1999; Sowell et al., 2001).

One consistent finding from all these studies is that the region with the most protracted developmental trajectory is the PFC, presumably supporting the repeated finding of remarkable improvement in more advanced cognitive skills and executive functions between childhood and adolescence (Fuster, 2002; Goldman-Rakic, 1989; Luciana & Nelson, 1998; Miller & Cohen, 2001; Paus, 2005; Romine & Reynolds, 2004; Wood & Grafman, 2003), and into early adulthood. This was a central finding in the study of DeLuca et al (2003), which investigated executive functions across the lifespan (i.e., 8 to 64 years) using a standard neuropsychological assessment battery. Performance improved from childhood into adulthood, reaching a peak between the ages of 20 and 29 years. This finding coincides with an earlier finding of Luciana and Nelson (2002), which showed significant improvement across the second decade of life in the realm of executive functions and specifically the processes of working memory including problem-solving, decision-making and planning (see also Casey et al., 2000; Romine & Reynolds, 2005; Rosso et al., 2004).

Also consistent with this conclusion is the trajectory of age-related development of working memory from childhood to old age. Researchers have demonstrated continued improvement across childhood and adolescence and into early adulthood. Swanson (1999), in a study of verbal and visuospatial working memory ability in participants ages 6 to 57, found lower performance for children and older adults compared to younger adults, in situations where the demand for accessing information and maintaining old information in working memory was high. In fact, verbal and visuospatial working memory peaked at age 45. Findings from other studies confirm this development of working memory into early- to mid-adulthood (Case, 1992, DeLuca et al., 2003; Luciana et al., 2005).

Goal-directed behavior is mediated not just by the process of working memory, but also by processes of attention allocation and inhibitory control or response suppression (Adleman et al., 2002; Case, 1992; Casey et al, 1995; Fuster, 2002; Kwon et al., 2002; Luciana et al., 2005; Luna & Sweeney, 2001; Miyake et al., 2000). All of these functions are presumably subserved by the PFC. Interestingly; several studies have demonstrated a pattern of greater PFC activation for children who have underdeveloped neuronal circuitry. Casey et al. (1997), tested children aged 9 to 11 years in a non-spatial 2-back memory task. The results from this study were compared to the findings of a similar memory task, which Cohen et al. (1994) used to test adults. While activation was seen in the PFC in both children and adults during task performance, activation in the PFC was greater in children. This was perhaps due to a greater error rate in children whose reliance on the PFC increased as the magnitude of task difficulty increased. Adults were able to make use of a more fully developed brain circuitry (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2001; Casey et al., 1997, 2001; Luna et al., 2000; Nelson et al., 2000; Papusek & Schulter, 2004; Pasingham & Toni, 1996; Rubia et al., 2000). This developmental finding has also demonstrated in electrophysiological studies using various behavioral measures of frontal lobe functioning (Davis, Gavin, & Segalowitz, 2002; Segalowitz

& Davis, 2003), as well as in non-human primates studies (Funahashi et al., 1991).

In several of the studies discussed thus far, the central finding has been that cognitive abilities, particularly those higher-order functions such as multi-tasking, increases with age (Rosso et al., 2004). Adolescents perform better than children do but not as well as adults. Although working memory is evident in children, the brain circuitry and neuronal network is not yet refined. Counterintuitively, greater activation is seen in the PFC of children and adolescents compared with adults during demanding WM tasks. Part of the explanation for increased processing efficiency and capacity in adults is the myelination process that is still occurring throughout even late adolescence and early adulthood (Casey et al., 2001; Giedd, 1999; Huttenlocher, 1979; Yakovlev & Lecours, 1967).

Decision-making ability is another PFC-related function that develops from childhood to adulthood. A modified version of the original gambling task (Bechara et al., 1994) has been widely used with children and adolescents as a test of decision-making ability. Crone & van der Molen (2004) tested 4 groups of individuals (6-8 years, 10-12 years, 13-15 years, and 18-25 years) on the gambling task as well on tests of working memory and inductive reasoning. They found age differences across the four groups in their ability to make correct choices and accurate predictions about beneficial future outcomes. The youngest group selected equally from both the advantageous and disadvantageous decks. The middle two groups showed a gradual improvement and towards the end of testing time were making more selections from the advantageous than the disadvantageous decks. Compared to these three groups, the oldest group displayed the highest ability to make good choices, which almost reached perfection by the end of the trials. Crone and van der Molen, drew a parallel between children performing this task and adults with VMPFC damage who share the same decision-making deficiencies, suggesting that the VMPFC is still underdeveloped in children. According to Crone and van der Molen, the increase in decision-making ability was not related to changes in working memory and inductive reasoning, providing additional support for the distinction between these functions (Bechara et al., 2004).

Of particular relevance to the current study is the pattern of maturation of the DLPFC and VMPFC. This is seen in a study by Hooper et al (2004), which tested adolescents' PFC-related abilities, using WM and behavioral inhibition tasks to tap the DLPFC and the IGT as a measure of the VMPFC in three age groups, which spanned from 9 to 17 years old. Age differences for DLPFC and VMPFC measures were found in all three groups. In the IGT task, age differences in the groups were similar to those found by Crone and van der Molen (2004), with the oldest group making more good choices in selecting from the advantageous decks compared to the younger groups. The study also found that there was no association between working memory and performance on the IGT. Skills required for working memory and inhibition were evident earlier in the life span than the skills required for performance on the IGT. Findings from this study indicate that the two PFC regions may have their own distinct developmental period of maturation.

Related to performance in the gambling task, an underdeveloped VMPFC along with a generally underdeveloped neuronal network can make adolescents, more so than adults, vulnerable to inappropriate risk-taking and impulsivity. Accordingly, impulsive and reckless behavior has been shown to be higher in adolescence and early adulthood (Chambers, Potenza, & Taylor, 2003). Gardner and Steinberg (2005) showed similar findings in a study with three groups of individuals (13-16 years, 18-22 years, and 24 and older) who executed risk preference and risk-taking decision measures alone and with peers. It was found that adolescents displayed a much higher tendency for risk-taking than adults do and did so more in peer groups than alone. The problem of gambling is two to four times higher in adolescents and young adulthood than in later adulthood (Chambers, et al., 2003). Individuals who are substance abusers as well as those who suffer from addictions have similar deficiencies as those individuals with VMPFC damage (Bechara et al., 2000). Dysfunction, damage, or underdevelopment of the VMPFC can lead to personality and psychopathological disorders. These important consequences support the further investigation of adolescence and early adulthood as a period of continued maturation of the VMPFC.

Whereas a great number of studies have focused on the structures and functions of the PFC, as well as its developmental trajectory, less research has concentrated on the idea that the development of the PFC can be influenced by environmental factors. Both the period of adolescence as well as the period of early adulthood makes it vulnerable to the demands and constant changes in the environment, resulting in a potential susceptibility to life stress. Research shows that the effects of life stress in adolescence and early adulthood can have an impact on cognitive development.

Life Stress and Cognitive Development

Selye (1956) viewed stress as a body’s response to the demands of any new event or change in life (Vinokur & Selzer, 1975). The PFC has been shown to be sensitive to stress (Arnsten, 1998; Arnsten & Shansky, 2004; Dahl, 2004). Research shows that stress impairs working memory, and leads to deficits in sustaining attention and inhibition of responses (Arnsten, 1998), and this may be significantly so during the period of adolescence, which is often characterized as an especially stressful stage in the life span (Spear, 2000) when the individual is going through a developmental transition (Arnsten, 1998, 2000; Arnsten & Shansky, 2004; Bar-

Tal et al., 1999; Bremner, 1999; Darke, 1988; Gerritis et al., 2003; Hains & Szyjakowski, 1990; Spear, 2003; Selye, 1956; Teicher et al., 2003). Stress could include both daily hassles and major life changes (Compass, 1987). Daily hassles, viewed as chronic stress (Compass, 1987), could even have a greater negative impact than major stressors or life changes (Compass, 1987; Hankin, Fraley, & Abela, 2005). Although stress can be useful and is at times important for survival, prolonged stress can have detrimental effects on cognitive functioning (Bremner et al., 1993; de Kloet, Oitzl, & Joels, 1999).

Several studies with animals as well as humans have shown that prolonged and extreme stress during the early years in the life span can have a debilitating effect on cognitive functioning and may alter normal brain development (Bremner & Narayan, 1998; Frick & Fernandez, 2003; Sapolsky, 1996; Shelline 2003; Teicher et al., 2003). A stressful environment during specific, sensitive periods affects important developmental processes including synaptic overproduction and pruning, and myelination. This can impede PFC maturation (Arnsten, 2000; Arnsten & Shansky, 2004; Bar-Tal et al., 1999; Bremner, 1999; Darke, 1988; Diamond et al., 1996; Gerritis et al., 2003; Spear, 2003; Selye, 1956; Teicher et al.).

Studies of humans and animals who have experienced extreme stress have revealed damage to several brain functions and structures (DeBellis et al., 2002; Sapolsky, 1996). Higher cognitive functions can be impaired when an individual is facing stress, leading to reduced functions of judgment and decision-making, problem-solving, social skills, and general goal-directed behavior (Eran & Daniel, 2003; Faigel, 1991). DeBellis et al (2002), examined children and adolescents with post-traumatic stress disorder. Their study found that when compared to normal controls, individuals exposed to severe chronic stress had a smaller PFC mass as well as less PFC white matter and deficits in several brain areas. This is indicative of the effects of chronic and severe stress on brain development.

The underlying neurobiological factors in adolescence make this life period vulnerable to stress (Arnsten, 1998; Arnsten & Shansky, 2004). Stress can prompt an imbalance in the neurotransmitters resulting in an increase in dopamine input (Arnsten & Shansky; Dahl, 2004; Spear, 2003), and this can in turn lead to cognitive deficits and damage (Gilberto et al., 2000; Spear). Research shows that dopamine plays a large role in the function of the DLPFC (Diamond, 2001; Rakic, 1992; Spear; Zellazo & Muller, 2002). During adolescence and adulthood, a dopamine imbalance could lead to deficits in working memory, attention allocation, inhibitory control, functions mediated by the DLPFC. This may then lead to impulsivity and poor judgment, which are behaviors often seen during this period (Spear, 2003). In addition, the impact of stress on emotional cognition, being mediated in part by the VMPFC, could also cause impairment in cognitive and social skills (Arnsten & Shansky; Dahl).

The large number of transitions faced by adolescents can expose them to a chronic state of homeostasis imbalance and threat (Arnsten & Shansky, 2004). Excessive cortisol productions brought on by stress leads to cognitive dysfunction as well. Cortisol hinders memory consolidation and retrieval (Faigel, 1991). Physiological studies have found a link between stress and PFC maturation. However, psychological studies have not yet focused on the specific link between life stress and PFC development in late adolescence and early adulthood. As another goal of the current study, I therefore examined whether life stress could be a correlate of PFC functioning for people aged 18 and 22-25 years old.

Overview of the Current Study

Based on the literature showing that the development and maturation of the prefrontal cortex (PFC) continues beyond adolescence, and is completed only in early adulthood, the current study proceeded to investigate the extent to which we can detect development of the PFC into early adulthood using common behavioral tasks of PFC functioning. I therefore examined two age groups, 18–year-olds and 22- to 25-year-olds, chosen to reflect the continuation and possible culmination of PFC maturation, with the hypothesis that the older group would outperform the younger group on PFC measures. Also, because research suggests later development of the DLPFC compared to the VMPFC, I also analyzed the magnitude of age differences in tasks predominantly tapping the DLPFC and the VMPFC.

Insights and information gained from structural and functional brain imaging research provide a detailed and distinct picture of the living brain, evidencing its growth and development especially through the adolescent years. However, assessing brain development by means of neuroimaging measures is expensive, resulting in small sample sizes, which can hamper a generalization of findings (Keating, 2001). In lieu of this kind of methodology, the use of psychological tests and assessments has been used and "their validity has been strong and compelling and comparable to medical tests" (Meyers et al., 2001, p. 128).

Although the nature of executive functions makes it hard to find precise measures that selectively tap each cognitive function (Ozonoff, 2001), the present study utilized common cognitive tests of PFC functioning. Each of these tests has been examined in neuroimaging studies to demonstrate its predominant reliance on the VMPFC or the DLPFC. Two measures (i.e., the 3-Back task and the SOPT) predominantly tap the DLPFC, and two measures (i.e., Faux Pas task and IGT) predominantly tap the VMPFC (see MacPherson et al., 2002). These four tasks were administered to participants in both age groups, in order to examine if functional differences in PFC functioning could be detected between the ages of 18 and 22-25 years.

As indicated in the literature, stress appears to negatively affect brain maturation, especially during the period of adolescence and early adulthood. To explore this theory, a life stress scale was administered to both the age groups to assess the extent to which life stress may be correlated with PFC maturation.

To summarize, I made three major empirical predictions: (1) There will be age differences in frontal lobe functioning between the two age groups; (2) There will be larger age effects in the DLPFC tasks compared to the VMPFC tasks; and (3) Life stress will be related to PFC functioning in these age groups.

Method

Participants

A total of 39 participants took part in the study. The 'younger group' consisted of 21 participants, 9 male and 12 female, who were 18 years old. The 'older group' consisted of 18 participants, 6 male and 12 female who were between 22 and 25 years old. All participants were Marietta College students who received 1.5 hours of course credit in exchange for their participation in the study. The two groups differed in the number of college years completed (younger group: $M = 1.39$, $SD = 1.10$; older group: $M = 4.39$, $SD = 1.13$), $F(1, 37) = 69.83$, $p < .001$, but not in GPA (younger group: $M = 3.25$, $SD = 0.44$; older group: $M = 3.08$, $SD = 0.48$), $F(1, 37) = 1.36$, $p = .252$. One younger group participant did not report a GPA; thus, all analyses related to GPA were conducted with $N = 38$.

In a correlation analysis, with age partialed out, no significant correlations were observed between demographic variables and PFC measures. However, when examining the relationships among demographic variables and stress measures, with age partialed out, GPA was significantly correlated with the negative stress score since age 11, $r(36) = -.42$, $p = .009$. A significant correlation was also observed between GPA and the total stress score since age 11, $r(36) = -.37$,

$p = .024$.

Materials

This study included four commonly used behavioral measures of frontal lobe functioning. Two of these measures (SOPT, and the 3-Back task) predominantly tapped the DLPFC, and the other two measures (Faux Pas task, and the IGT) predominantly tapped the VMPFC. In addition, a survey measuring life stress (LES) was administered.

DLPFC Measures

The Self-Ordered Pointing Task (SOPT)

The SOPT (Petrides & Milner, 1982) consisted of a booklet containing three trials, each with 15 pages of non-verbal stimuli. Each page displayed the same 15 different abstract designs, but in differing spatial arrangements. To demonstrate the task and explain the instructions, participants were first guided through one practice set. Participants then completed three full sets, or trials.

At the start of each trial, participants were told to point to all the stimuli presented on the first page, one at a time, and in any order they wished, but without touching any given stimulus more than once. On each subsequent page, participants had to point to a different design. Participants were instructed that they were not allowed to pick items from the same locations on subsequent pages, and were informed that accuracy and not speed was important. At the end of the task participants were asked if they had used a particular strategy to help keep track of the designs, and their responses were noted. The total proportion of unique items selected, averaged across the three trials, was the main dependent measure.

The 3-Back Task

The 3-back test (Cohen et al., 1994; Dobbs & Rule, 1989; D’Esposito et al., 1995;

Jonides et al., 1997) presented one letter at a time on the computer screen. The task was comprised of four sequences (i.e., trials). Each sequence was composed of 30 letters, with each letter presented for 750 ms, and a 1200 ms interstimulus interval.

Participants were required, for each current letter, to decide whether it matched the one presented 3 items previously. For the first three letters of a sequence, participants responded by pressing the "NO" key. For each subsequent letter, participants pressed the "YES" key for stimuli that matched the identity of the 3-back item, or the "NO" key for those that did not match the 3-back item. The dependent measure of interest was the total proportion of correct responses averaged across the four trials, not counting the first three responses on each trial.

VMPFC Measures

The Iowa Gambling Task (IGT)

The IGT (Bechara et al., 1994) is a laboratory version of real-life decision-making and simulates the evaluation of risks and rewards as relevant to future outcomes. Participants attempt to win as much money as possible, while minimizing losses, by choosing from decks of cards that have different win/loss ratios. In the original task, participants were given a loan of play money at the start of the game and asked to maximize their profits.

The current study employed a computerized version of the IGT. There were two advantageous decks, and two disadvantageous decks. The two advantageous decks (i.e., C and D) yielded low profits and no losses. The other two decks (i.e., A and B) were ultimately disadvantageous by yielding high immediate gains but also high losses.

Participants were shown four decks of playing cards on the computer screen and were given a loan amount of $2000 to start. They were told to select one card at a time from any deck of their choice by moving the pointer with the mouse, over a card and clicking on the mouse.

Participants were required to keep making the card selections and were free to switch from deck to deck at any time. The participants were not told ahead of time how many card selections they had to make; thus, they had to continue to maximize their profits without knowing when the task would end. Each card that was drawn resulted in some amount of monetary gain, although some cards also came with a loss. The game ended after 100 cards had been chosen.

The computer program represented monetary gain and loss by adding and subtracting poker chips from the screen. White chips were worth $25, red chips were worth $50 and blue chips were worth $100. At the end of the game the loan amount of $2000 was subtracted from the final total, revealing how much the participant had won or lost. This final monetary total, as well as the proportion of cards selected from the advantageous decks, were used as dependent measures.

The Faux Pas Task

In the Faux Pas task (Stone et al., 1998), participants listened to an oral presentation of a series of stories, and were asked to respond to questions at the end of each story. A booklet with the stories was given to the participant and they were allowed to follow along, as well as refer to the story in order to answer the questions.

The booklet consisted of 20 short stories. Ten of these stories contained a faux pas, or social slip, and 10 did not (see Appendix A). Each faux pas story contained a situation in which one of the characters, the'protagonist,' said something socially awkward or inappropriate that was hurting or upsetting to another character in the story (MacPherson et al., 2002). Participants were allowed to read the stories as many times as they wanted to. There was no time limit. At the end of each story, questions about the intentions of the person in the story making the faux pas were presented along with a control question, to make sure that the participant clearly understood the story and is aware that a faux pas was committed. Answers were scored as correct if the participant showed a clear understanding that the ‘faux pas’ made by the person was unintentional, but at the same time it could hurt or upset another character in the story. Answers that implied that the faux pas was intentionally made were scored as incorrect. The dependent measure of interest was the mean proportion correct of faux pas questions.

Life Stress Measure

The Life Experience Survey (LES; Sarason et al.,1978) (see Appendix B) is a 57-item self-report measure assessing positive and negative life experiences experienced in the past year as well as the degree of impact of these experiences on the individual (Sarason et al., 1978).

The LES is comprised of two sections. The first section contains 47 items that referred to events or life changes that were common to individuals in a wide variety of situations. This section is appropriate for use with a general population. The second section contains 10 items that specifically deal with changes experienced in the academic environment, and hence relevant to a student population. Although two test-retest reliability studies showed that this is a moderately reliable instrument, the LES does seem to have sufficient reliability, and in addition, has acceptable validity, based on correlations with other life stress measures and with academic achievement (Sarason et al., 1978). The finding of the LES as being moderately reliable was perhaps due to a low sample size of the study and also due to the "test- retest reliability coefficients that are found with instruments of this type , that could have underestimated the reliability of this measure" (Sarason et al, p.936). According to Sarason et al., the validity of the LES more importantly reflects three main features that provide at least face validity for a measure of life stress: (1) a list of events experienced with at least some degree of frequency in the population being investigated; (2) ratings by the respondents themselves as to the desirability or the undesirability of the events; and (3) individualized ratings of the personal impact of the events experienced. These features make the LES a far better tool (compared to several other measures used to assess life stress) in determining the extent and degree of life stress faced by an individual (Sarason et al.).

For the current study, all 57 items of the LES were included. The format of the LES required the subject to rate separately the occurrence and impact of events they had experienced within the last year. Given the hypothesis that stressful experiences occurring earlier in adolescence may be related to prefrontal cortex functioning, the survey was also administered with the instruction to indicate if the participants had experienced any of the events since the age of 11 years. This age period is reflective of the start of adolescence. Data from this set of responses provided information about of the impact of stressful experiences faced by the individual during adolescence through early adulthood.

The different events on the LES may or may not have entailed a life change for the participants. Hence, if the event did have an impact, the participant was required to rate the extent of it, and whether it had a positive or negative impact on their life.

Participants rated the impact of the events they had experienced on a 7-point scale with the following options: *extremely negative* (- 3), *moderately negative* (-2), *somewhat negative* (-1), *no impact* (0), *slightly positive* (+1), *moderately positive* (+2), and *extremely positive* (+3). Measures of interest for the current study included: (1) the total number of potentially stressful events experienced, both in the past year (*LES Total – Past year*), and since the age of eleven years (*LES Total – Since Age 11*); (2) the sum of the positive change scores, from events experienced in the past year (*LES Positive –Past Year*), and also since the age of eleven years (*LES Positive - Since Age 11*); and (3) the sum of the negative change scores, from events experienced in the past year (*LES Negative – Past Year*), and also since the age of eleven years (*LES Negative – Since Age 11*).

Procedure

Participants were tested individually in one session lasting between 60 and 90 minutes. Before participating in the study, each participant signed an informed consent form, and completed a short demographic questionnaire, including questions about gender, GPA, and number of college years completed. Next, the four frontal lobe tasks were administered in a counterbalanced order, alternating between paper (i.e., SOPT and Faux Pas) and computer (i.e., IGT and 3-Back) tests. Following these tasks, participants completed the LES, using a black pen to indicate their responses for events within the past year, and a red pen to indicate their responses for events occurring since the age of eleven.

At the completion of the session participants were fully debriefed.

Results

Preliminary data analysis included descriptive statistics (e.g., mean and standard deviation) for each measure used in the study, and for each age group separately. For analyses requiring composite measures of PFC functioning, such measures were computed based on the mean *z*-scores for the relevant tasks.

All inferential statistical tests used an alpha level of .05. Effect sizes for analyses of variance (ANOVAs) were estimated using η^2, and in keeping with Cohen's (1988) guidelines, .01 was considered to be a small effect, .06 a medium effect, and .14 a large effect. For the partial correlation analyses, an r value of .10 was considered to be a small effect, .30 a medium effect, and .50 a large effect; for the hierarchical regressions, an R^2 value of .02 was a small effect, .13 a medium effect, and .26 a large effect.

DLPFC Tasks

SOPT

A 3 (SOPT trial) x 2 (Age group) ANOVA was computed, using the proportion of unique designs chosen as the dependent variable. The analysis revealed a significant main effect of age, $F(1, 37) = 5.74$, $p = .022$, $\eta^2 = .13$, such that the older group outperformed the younger group, but no main effect of trial, $F(2, 74) = .29$, $p = .752$, $\eta^2 = .01$ (see Table 1). However, a significant interaction was observed between age and trial, $F(1, 37) = 3.64$, $p = .031$, $\eta^2 = .09$. This interaction was driven by a significant age difference in trial 1 (younger group: $M = .84$, $SD = .11$; older group: $M = .93$, $SD = .05$), $F(1, 37) = 11.63$, $p = .002$, $\eta^2 = .24$, but not in trial 2 (younger group: $M = .87$, $SD = .09$; older group: $M = .89$, $SD = .09$), $F(1, 37) = 0.77$, $p = .387$, η^2 .02, or in trial 3 (younger group: $M = .86$, $SD = .08$; older group: $M = .89$, $SD = .06$), $F(1, 37) = 2.46$, $p = .125$, $\eta^2 = .06$). Even though the older group's advantage was significant only on Trial 1, the fact that the older group numerically outperformed the younger group on all trials justifies the use of the overall mean proportion correct as the dependent measure for subsequent analyses.

3-Back Task

A 4 (3-Back trial) x 2 (Age group) ANOVA using the proportion of correct responses as the dependent variable revealed no significant main effect of age, $F(1, 37) = 0.37$, $p = .546$, $\eta^2 = .01$, nor of trial, $F(3, 111) = 1.11$, $p = .347$, $\eta^2 = .03$, and no significant interaction, $F(3, 111) = 1.92$, $p = .128$, $\eta^2 = .05$. Numerically speaking, the mean for the younger group ($M = .76$, $SD = .08$), was only slightly lower than the mean for the older group ($M = .78$, $SD = .07$) (See Table 1).

DLPFC Age Differences

To analyze age differences across the two DLPFC tasks, a 2 (DLPF task: SOPT, N-Back) x 2 (Age Group) ANOVA was calculated. The mean *z*-scores for each DLPFC task were used as the dependent variable. While the analysis revealed no significant main effect of task, $F(1, 37) = 0.01$, $p = .923$, $\eta^2 = .000$, a trend towards significant effect of age was found, $F(1, 37) = 3.89$, $p = .056$, $\eta^2 =. 10$, with the older group outperforming the younger group overall. No significant interaction was observed, $F(1, 37) = 1.59$, $p = .217$, $\eta^2 = .04$.

VMPFC Tasks

The Faux Pas Task

A 2 (Question type: control, faux pas) x 2 (Age group) ANOVA was calculated, using the proportion of correct answers as the dependent variable. The analysis revealed a significant main effect of age, $F(1, 37) = 14.40$, $p = .001$, $\eta^2 = .28$, but only a trend towards a main effect of question type, $F(1, 37) = 3.08$, $p = .09$, $\eta^2 = .08$ (see Table 1). The main effects were qualified by a significant interaction between age and question type, $F(1, 37) = 5.01$, $p = .031$, $\eta^2 = .12$, driven by the older group outperforming the younger group on the faux pas questions (younger group: $M = .82$, $SD = .15$; older group: $M = .97$, $SD =. 05$), $F(1, 37) = 18.80$, $p < .001$, $\eta^2 = .34$, but no significant age differences for the control questions (younger group: $M = .91$, $SD = .13$; older group: $M = .96$, $SD = .10$), $F(1, 37) = 1.83$, p = .185, $\eta^2 =.05$. In light of the fact that it is the faux pas questions, rather than the control questions, that predominantly tap the VMPFC (Stone et al,1998), in subsequent analyses, the mean proportion correct for all the faux pas questions was used as the dependent variable for the Faux Pas task.

IGT

A one-way ANOVA assessed age differences in the proportion of selections from the advantageous decks. The main effect of age only approached significance, $F(1, 37) = 3.19$, $p = .082$, $\eta^2 = .08$ (younger group: $M = .56$, $SD = .08$; older group: $M = .60$, $SD = .09$) (see Table 1).

A second ANOVA using the final money score as the dependent variable also revealed a trend towards a significant age effect (younger group: M = -192.86, SD = 622.20; older group: M = 179.97, SD = 738.40), $F(1, 37) = 2.99$, p =.096, $\eta^2 = .07$. Numerically speaking, the older group outperformed the younger group using both dependent measures. For subsequent analyses, in keeping with prior literature (e.g., Bechara et al., 1994), the mean proportion of cards chosen from the advantageous decks was used as the dependent variable.

VMPFC Age Differences

To analyze age differences in the VMPFC tasks, a 2 (VMPFC task: Faux Pas, IGT) x 2 (Age group) ANOVA was calculated. The mean *z*-scores for each VMPFC task were taken as the dependent variables. The analysis revealed a significant main effect of age, $F(1, 37) = 18.12$ $p < .001$, $\eta^2 = .33$, indicating overall higher scores for the older group. There was, however, no main effect of task, $F(1, 37) = 0.01$, p =. 914, $\eta^2 = .00$, nor was there an interaction, $F(1, 37) = 2.00$, $p = .166$, $\eta^2 = .05$.

PFC Age Differences

To determine whether there was a differential age effect for tasks tapping the two PFC regions under investigation, a 2 (PFC area: DLPFC, VMPFC) x 2 (Age group) mixed-factor ANOVA was computed using the composite standardized measures for DLPFC (i.e., the mean z-scores for the SOPT and 3-Back tasks) and VMPFC (i.e., the mean z-scores for the IGT and Faux Pas tasks) functioning. The analysis revealed a main effect of age group, $F(1, 37) = 14.17$, $p = .001$, $\eta^2 = .28$, indicating superior performance for the older group overall. However, there was no main effect of brain region, $F(1, 37) = .014$, $p = .906$, $\eta^2 = .00$, nor was there an interaction between the factors, $F(1, 37) = 2.41$, $p = .129$, $\eta^2 = .06$. See Table 2 for correlations among the PFC tasks.

Life Stress

To determine if life stress could be a mediating factor in PFC functioning and maturation, two types of analyses were conducted. The first analysis looked at stress measures as covariates in the relationship between age group and PFC functioning. The second series of analyses examined stress measures as predictors of PFC functioning for both age groups combined.

Six 2 (DLPFC, VMPFC) x 2 (Age) analyses of covariance (ANCOVAs) were conducted with each of the stress measures (i.e., *LES Total - Past Year, LES Positive – Past Year, LES Negative - Past Year, LES Total – Since Age 11, LES Positive – Since Age 11, and LES Negative – Since Age 11*) as individual covariates. In each of the six analyses, the main effect of age remained significant (all *p*s $< .05$), and the main effects of brain region and the interactions remained non-significant (all *p*s $> .05$). Only one ANCOVA, which included *LES Positive – Since Age 11*, showed stress to be a significant covariate, $F(1, 36) = 9.34$, $p = .004$, $\eta^2 = .21$. A similar trend towards significance was also observed in the ANCOVA including the *LES Total – Since Age 11* as the covariate, $F(1, 36) = 3.05$, $p = .089$, $\eta^2 = .08$.

Regression analyses were also computed to determine the extent to which stress was predictive of PFC functioning with both age groups combined (see Table 2 for correlations among stress measures and PFC tasks). The dependent measure for all the regression models in these analyses was the mean *z*-scores of all four PFC measures included in the study. There were three components to this analysis: (A) regression models examining the contribution of *LES Total - Past Year, LES Positive – Past Year,* and *LES Negative - Past Year*, as individual predictors of PFC functioning, and as combined predictors of PFC functioning (Models 1 - 4); (B) regression models examining the contribution of *LES Total – Since Age 11, LES Positive – Since Age 11,* and *LES Negative – Since Age 11*, individually, and as combined predictors of

PFC functioning (Models 5 - 8); and (C) regression models hierarchically examining the contribution of *LES Total, LES Positive,* and *LES Negative - Since Age 11* above and beyond the contribution of those measures within the past year (Models 9 - 11). See Table 3 for the regression results of the models described.

In the models for Part A, regression analyses were first conducted to examine the total stress score, the positive stress score, and the negative stress score for the past year as separate predictors of PFC functioning. *LES Positive – Past Year* was the strongest predictor of PFC functioning, contributing approximately 8% of the variance in PFC functioning, $R^2 = .081$, $p = .079$ (see Model 2 in Table 3). *LES Total – Past Year* contributed nearly 6% of PFC variance, $R^2 = .057$, $p = .142$ (see Model 1), but the *LES Negative –Past Year*, only predicted 1% of PFC variance, $R^2 = .009$, $p = .566$ (see Model 3). A simultaneous regression model was then conducted to determine the predictive power of these three stress scores together (see Model 4). However, the *LES Total –Past Year* was excluded from the analyses as it was redundant (i.e., highly correlated) with *LES Negative – Past Year* (r (37) = .811, $p < .001$, see Table 2). The combined model accounted for nearly 9% of the variance in PFC functioning, $R^2 = .087$, $p = .194$.

Part B of the regression analysis examined the stress variables measured since age 11 by analyzing *LES Total – Since Age 11*, *LES Positive – Since Age 11*, and *LES Negative – Since Age 11* as separate predictors of PFC functioning (see Models 5, 6, and 7 in Table 3). The analysis revealed no significant predictors of PFC functioning (all *p*s > .10). A simultaneous regression was then conducted to analyze these three stress scores together. Combined, the stress scores measured since age 11 contributed 9% of variance in PFC functioning, $R^2 = .091$, $p = .335$ (Model 8).

The third component, Part C, examined the stress scores at both of the time intervals measured. This hierarchical analysis was conducted to assess the contribution of stress scores since the age of 11 above and beyond those from the past year. *LES Total – Since Age 11* did not significantly contribute to PFC functioning above and beyond *LES Total – Past Year* (p = .389, Model 9 in Table 3). Similarly, *LES Positive – Since Age 11* was not predictive of PFC functioning beyond *LES Positive – Past Year* (p = .650, Model 10). However, *LES Negative – Since Age 11* did contribute a nearly significant 10% of PFC variance beyond *LES Negative - Past Year* (p = .052, Model 11). This model, compared to the regression models presented previously, showed the strongest prediction of PFC functioning from life stress measures., accounting for a total of 10.9% variance in PFC functioning, p = .125.

Discussion

The central purpose of this study was to investigate the extent to which the functional development of the PFC between late adolescence and early adulthood can be detected in commonly used behavioral measures of PFC functioning. This study was conducted in light of past findings from post mortem and neuroimaging studies as well as behavioral measures, suggesting that the development and maturation of the PFC continues beyond adolescence, and is completed only in early adulthood (Anderson et al. 2001; De'Luca et al., 2003; Fuster & Alexander, 1971; Giedd et al., 2000, 2004; Gogtay et al., 2004; Huttenlocker, 1990; Paus, 2005; Rainer & Ranganath, 2001; Romine & Reynolds, 2005; Sowell et al., 1999, 2002). To this end, the present study examined two age groups. The younger group (18 years old) represented a stage of ongoing brain development and the older group (22 to 25 years old) represented the culmination or near-culmination of brain development. The central hypothesis of this study was that the older group would outperform the younger group on PFC measures.

By examining potential developmental differences in these two 'early adult' age groups, this study has added something new to the accumulating evidence of the types of cognitive maturation that take place during this period between late adolescence and early adulthood. While several studies examining the performance of PFC functions have examined participants in this age range as a single group, the current study has contrasted them as two separate age groups, thereby providing a fine-grained analysis into this time period of development. This type of investigation is particularly important because of the role of the PFC in executive functions that underlie everyday tasks. An underdeveloped PFC can result in inefficient life skills via cognitive and social immaturity as seen in deficits in decision-making and planning, incompetence in reasoning, evaluating risk and reward, making judgments under conditions of uncertainty, WM, allocation of attention resources, inhibitory control, and impulsive behavior. All of these are functions which were measured by the different tasks in this study, and in which the PFC plays a critical role (e.g, Casey et al., 2000; Case, 1992; Diamond & Goldman, 1989; Duncan, 1986; Fuster, 1989; 2002; Holyoak & Kroger, 1995; Luciana & Nelson, 1998; Luria, 1966; Miller & Cohen, 2001; Miyake et al., 2000; Sowell et al., 1999; Stuss, 1992).

A significant improvement in these executive functions has been found across the second decade of life (Luciana & Nelson, 2002), specifically in the processes of working memory, which are important for such higher-order abilities as problem-solving, decision-making, and planning (Anderson et al., 2001; Casey et al., 2000; Luciana and Nelson 2002; Romine & Reynolds, 2005; Rosso et al., 2004). Hence, a better understanding of this developmental period in the life span can be crucial, especially when viewed in the context of college, workforce, and social group environments involving this young adult age group.

In support of the central hypothesis of the study, the results of the analysis examining age differences using a composite measure of PFC functioning revealed significant age differences, with the older group outperforming the younger group. This finding is consistent with prior research suggesting that brain development and maturation specifically that of the PFC, continues through adolescence and into early adulthood (Bechara, 2004; De Luca et al., 2003; Fuster, 2002; Giedd et al., 1999; Gogtay et al., 1999; Huttenlocher, 1990; Luna & Sweeney, 2001; Paus et al., 2001; Sowell, 2001, Wood & Anderson, 2003).

The second purpose of this study was to analyze the magnitude of age differences in tasks selectively tapping the DLPFC and the VMPFC. Research has suggested that these two distinct regions (MacPherson et al., 2002; Wood & Grafman, 2003) may show different developmental trajectories, with later development of the DLPFC compared to the VMPFC (Diamond, 2001; Diamond & Goldman, 1989; Fuster, 2002; Giedd, 1996; Gogtay et al., 2004; Happaney et al., 2001; Huttenlocher, 1979; Paus, 2005). In light of these theories, in the current study, it was hypothesized that there would be larger age effects in the DLPFC tasks compared to the VMPFC tasks, such that the older group would outperform the younger group on the DLPFC tasks by a larger margin than on the VMPFC tasks.

Although there were age differences overall in the PFC tasks, there was no support for this second hypothesis of the study. There were similar age effects for tasks tapping the two brain regions; and, if anything, VMPFC tasks showed numerically larger age differences. Interestingly, this latter finding was reflective of the Faux Pas task. The older group was more adept at detecting a faux pas than the younger group. The findings may be indicative of the fact that social cognition, a function measured in the Faux Pas task and mediated by the VMPFC (Bechara et al., 2000; Krawzyk, 2000), may still be developing and does not seem to be complete before early adulthood (Hooper et al., 2004).

As espoused by Bechara (2004), the development of the PFC, specifically functions such as decision-making, do not develop until early adulthood. Although the low power of this study resulting from the small sample size limits the interpretability of this finding, it is in line with some research suggesting that the VMPFC may be on a similar developmental timeline as the DLPFC (Crone & van der Molen, 2004; Hooper et al., 2004). Future research should explore this possibility.

Although the overall age differences in composite PFC measures suggests continued development within the age frame of the study's participants, certain of the PFC tasks administered in this study appeared to be more sensitive to these age differences. For example, as stated above, the significant main effect of age in composite VMPFC functioning score was driven mainly by age differences in the Faux Pas task. For the other VMPFC task included in this study, the IGT, there was only a statistical trend towards age differences. Prior studies examining children, adolescents and adults (Hooper et al., 2004; Crone & Molen, 2004) have shown that while IGT age differences existed with all three groups, the oldest group had the highest selection of card choices from the advantageous decks. This study found a similar pattern, even though it failed to reach statistical significance. The overall conclusions from age effects in the VMPFC tasks support the further investigation of adolescence and early adulthood as a period of continued maturation of this brain region.

Risk-taking behaviors are also seen to be prominent in adolescence and early adulthood (Gardner & Steinberg, 2005), and studies have shown that an underdeveloped VMPFC can make adolescence and early adulthood vulnerable to inappropriate risk-taking and impulsivity (Chambers et al., 2003; Gardner & Steinberg). Other consequences of such deficits in risk assessment (as measured by the IGT) and social cognition (as measured by the Faux Pas task) should be studied in more detail in this age range.

In the composite DLPFC functioning measure, the SOPT was more reflective of age differences than the 3-Back task. A significant main effect of age was detected in the SOPT overall; however, detailed analyses showed that the age effect was significant only in Trial 1, and not in Trials 2 and 3. This finding is particularly interesting in light of prior research showing that the task becomes increasingly difficult as the trials progress (Petrides & Milner, 1982). In the context of this study, this suggests that on the first and easiest trial, the older group was able to outperform the younger group, but once the task increased in difficulty level, the age difference disappeared. Future research endeavors utilizing the SOPT with these age groups should be aware of this pattern. In the second DLPFC measure, the 3-Back task, the older group failed to outperform the younger group. This is particularly intriguing due to the absence of floor or ceiling effects, and the common use of this task in neuroimaging and developmental studies.

The failure to find a larger age effect for DLPFC tasks, compared to VMPFC tasks, seems to contradict the theory of a later maturation for the DLPFC (Fuster, 2002; Giedd, 1996; Gogtay et al., 2004; Paus, 2005). The pattern of results found in the current study may be related to several underlying factors. First, although the measures chosen for this study relied predominantly on the DLPFC (Petrides & Milner, 1982; MacPherson et al., 2002), there is the possibility of a lack of task purity that might have contributed to these findings. For example, the IGT is predominantly a VMPFC measure, but it also involves WM, strategy, and planning, all of which are functions subserved by the DLPFC, while the 3 Back task is predominantly a DLPFC measure but it also involves decision-making a function subserved by the VMPFC. There is always the possibility of these overlapping processes in cognitive development, although evidence from neuroimaging lends support that these tasks predominantly tap either the DLPFCS or the VMPFC. Thus, the lack of task purity may have confounded the detection of the younger group's still-developing DLPFC. Second, there could be an earlier maturation for the DLPFC itself. Third, there is the possibility that the development of a wider brain circuitry is already in place (which the younger group was able to adopt, leading to a decrease in load on the DLPFC). This can compensate for DLPFC deficits leading to a decrease in the error rates (see Hooper et al., 2004; see also Crone & van der Molen, 2004). However, the low power of this study limits the interpretability of the above findings.

Although there was a lack of support for the age differences in brain region, the overall findings seem to establish that the development and maturation of the PFC continues into early adulthood. With a larger sample we could probably detect more distinct age differences, and be able to establish a better developmental trajectory for the DLPFC and the VMPFC. While numerically the older group did perform better than the younger group on all the measures, as espoused earlier a larger sample could probably nudge the magnitude of age differences into even greater significance.

PFC maturation takes place in the context of individual environmental experiences. A final purpose of this study was to investigate the role of life stress as one environmental factor identified as impacting optimal brain development. Human and animal studies have shown the PFC to be sensitive to stress, and this is especially relevant during the transitional period between adolescence and adulthood (Arnsten, 1998; Arnsten & Shansky, 2004; Bar-Tal et al., 1999; Bremner, 1999; Dahl, 2004; Darke, 1988; Diamond, 2001; Gerritis et al., 2003; Teicher et al., 2003; Selye, 1956; Spear, 2000). An underdeveloped PFC can result in inefficient life skills via cognitive and social immaturity (Fuster, 2002; Krawzyk, 2002; Stuss & Levine, 2002). Hence, given that stress may negatively affect brain maturation, this study examined if life stress could be a mediating factor in the cognitive maturation of the PFC, and hence associated with lower PFC performance.

To investigate this hypothesis, life stress was measured in terms of total number of events and degree of positive or negative impact of events experienced in two time periods: (1) since the age of 11, and (2) within the past year. Consistent with predictions based on prior research, an analysis of the life stress scale revealed that stress faced during the adolescent years (i.e., since age 11) was overall more highly predictive of PFC functioning than stress faced in the immediate past. Brain development does not happen overnight. Hence, there is a greater impact (on a brain that is still developing) from the effect of events, specifically stress; which has accumulated overtime. This seems to indicate that the immediate daily hassles although viewed as chronic stress (Compass, 1987), do not have as great an impact on the brain as that of stress accumulated through the years. These findings of the effect of stress since the age of eleven years on the development of the PFC is important, and is in line with research that suggests that the PFC is sensitive to stress during the developmental years, especially during the transitional period from adolescence to adulthood. The PFC is malleable to learning and experience. Hence any stressful event during its developing stage could have a far greater an effect than any recent stressors.

Overall, the best predictive model of PFC functioning included two predictors: negative stress from the past year and negative stress since the age of 11. In addition to the combined predictive power of these two measures, it appears that negative stress since the age of 11 is an independent, unique, and better predictor of PFC functioning than the negative stress score from the past year. Although the regression findings from this study only approached statistical significance, they are nevertheless in line with prior research that has established that negative stress faced in adolescence can impact PFC functioning. Future research, using larger samples, should continue to investigate the possible link between life stress in adolescence and PFC functioning in young adulthood.

Although this study supported the hypothesis of age differences in PFC functioning between late adolescence and early adulthood, there were limitations. Prominent among the shortcomings of this study was a small sample size, and the fact that the sample used in this study was made up of a healthy college population. The latter is important in considering that the measures may not evoke the same findings as when used with a population where PFC deficits or damage to brain regions are present, as many of these tasks have been predominantly used with a non-normal sample (Bechara et al., 1994, Petrides & Milner, 1982). Even a less well-educated sample might make a difference in the detection of age differences. In the present study, the constraints of using a college population in a cross-sectional design also limited the age cohort and time period of testing. Increasing the sample size and replicating this study in a longitudinal design would increase the power of the findings and allow for the detection of a clearer picture of the PFC development into adulthood. An increase in sample size could also help in exploring more demographics and variables that may be associated with PFC functioning.

Insights and information gained from structural and functional brain imaging research provide a detailed and distinct picture of the living brain, evidencing the growth and development which support the remarkable improvement in advanced cognitive skills and executive functions across childhood and adolescence and into early adulthood (De'Luca et al., 2003; Fuster, 2002; Luciana & Nelson, 1998; Miller & Cohen, 2001; Paus, 2005; Romine & Reynolds, 2004). This study has added to existing evidence that the PFC does not complete development by late adolescence. Rather it is still developing into adulthood, and perhaps attaining maturation or optimal achievement of executive functions only in the third decade of life (Case, 1992; Casey et al., 2000; De Luca et al., Fuster; Huttenlocher, 1979; 1984, 1990; Sowell et al; 2002; Yakovlev & Lecours, 1967).

By confirming the presence of age differences in early adulthood using behavioral tests of PFC functioning, the findings from this study could extend towards future research in the neural underpinnings of behavior in late adolescence and early adulthood, which in turn could lead to a better understanding of this developmental period in the life span. In light of these findings, it is important to design effective behavioral methods to assess abilities mediated by the PFC, such as WM, attention allocation, judgment, planning, inhibitory control and decision-making. While an understanding of these functions can be two- fold. While enabling the assessment of areas in which adolescents and early adults are competent to make decisions, and when and at what age they are competent to make decisions. In the context of normal development, these findings can have other implications as well; such as determining what functions an average adolescent or young adult is capable of performing, and what level of maturity and development can be expected from such individuals. This is important when viewed in the context of activities such as driving, drinking (alcohol), and even school and work performance. The findings while providing a better understanding of this young adult age group can also be beneficial for developing interventions such as provisions for direction, opportunity, and perhaps eventually, it can even be used as a tool for neuropsychological assessment. Future studies need to address this continued development by more closely examining the younger adult age range.

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Appendix A

Faux Pas Recognition Test (Stone, Baron-Cohen, & Knight, 1998)

(Adult Version)

1. Vicky was at a party at her friend Oliver's house. She was talking to Oliver when another woman came up to them. She was one of Oliver's neighbors. The woman said, "Hello," then turned to Vicky and said, "I don't think we've met. I'm Maria, what's your name?" "I'm Vicky." "Would anyone like something to drink?" Oliver asked.

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Oliver know that Vicky and Maria did not know each other?

How do you think Vicky felt?

Control questions: In the story, where was Vicky?

Did Vicky and Maria know each other?

2. Helen's husband was throwing a surprise party for her birthday. He invited Sarah, a friend of Helen's, and said, "Don't tell anyone, especially Helen." The day before the party, Helen was over at Sarah's and Sarah spilled some coffee on a new dress that was hanging over her chair. "Oh!" said Sarah, "I was going to wear this to your party!" "What party?" said Helen. "Come on," said Sarah, "Let's go see if we can get the stain out."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Sarah remember that the party was a surprise party?

How do you think Helen felt?

Control questions: In the story, who was the surprise party for?

What got spilled on the dress?

3. Jim was shopping for a shirt to match his suit. The salesman showed him several shirts. Jim looked at them and finally found one that was the right color. But when he went to the dressing room and tried it on, it didn't fit. "I'm afraid it's too small," he said to the salesman. "Not to worry," the salesman said. "We'll get some in next week in a larger size." "Great. I'll just come back then," Jim said.

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When he tried on the shirt, did Jim know they didn’t have it in his size?

How do you think Jim felt?

Control questions: In the story, what was Jim shopping for?

Why was he going to come back next week?

4. Jill had just moved into a new apartment. Jill went shopping and bought some new curtains for her bedroom. When she had just finished decorating the apartment, her best friend, Lisa, came over. Jill gave her a tour of the apartment and asked, "How do you like my bedroom?" "Those curtains are horrible," Lisa said. "I hope you're going to get some new ones!"

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Lisa know who had bought the curtains?

How do you think Jill felt?

Control questions: In the story, what had Jill just bought?

How long had Jill lived in this apartment?

5. Bob went to the barber for a haircut. "How would you like it cut?" the barber asked. "I'd like the same style as I have now, only take about an inch off," Bob replied. The barber cut it a little uneven in the front, so he had to cut it shorter to even it out. "I'm afraid it's a bit shorter than you asked for," said the barber. "Oh well," Bob said, "it'll grow out."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

While he was getting the haircut, did Bob know the barber was cutting it too short?

How do you think Bob felt?

Control questions: In the story, how did Bob want his hair cut?

How did the barber cut his hair?

6. John stopped off at the gas station on the way home to fill up his car. He gave the cashier his credit card. The cashier ran it through the machine at the counter. "I'm sorry," she said, "The machine won't accept your card." "Hmmm, that's funny," John said. "Well, I'll just pay in cash." He gave her twenty dollars and said, "I filled up the tank with unleaded."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When he handed his card to the cashier, did John know the machine wouldn’t take his card?

How do you think John felt?

Control questions: In the story, what did John stop off to buy?

Why did he pay in cash?

7. Sally is a three-year-old girl with a round face and short blonde hair. She was at her Aunt Carol's house. The doorbell rang and her Aunt Carol answered it. It was Mary, a neighbor. "Hi," Aunt Carol said, "Nice of you to stop by." Mary said, "Hello," then looked at Sally and said,

"Oh, I don't think I've met this little boy. What's your name?"

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Mary know that Sally was a girl?

How do you think Sally felt?

Control questions: In the story, where was Sally?

Who came to visit?

8. Joan took her dog, Zack, out to the park. She threw a stick for him to chase. When they had been there a while, Pam, a neighbor of hers, passed by. They chatted for a few minutes. Then Pam asked, "Are you heading home? Would you like to walk together?" "Sure," Joan said. She called Zack, but he was busy chasing pigeons and didn't come. "It looks like he's not ready to go," she said. "I think we'll stay." "OK," Pam said. "I'll see you later."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When she invited her, did Pam know that Joan wouldn't be able to walk home with her?

How do you think Pam felt?

Control questions: In the story, where had Joan taken Zack?

Why didn't she walk with her friend Pam?

9. Joanne had had a major role in last year's school play and she really wanted the lead role this year. She took acting classes, and in the spring, she auditioned for the play. The day the decisions were posted, she went before class to check the list of who had made the play. She hadn't made the lead and had instead been cast in a minor role. She ran into her boyfriend in the hall and told him what had happened. "I'm sorry," he said. "You must be disappointed." "Yes," Joanne answered, "I have to decide whether to take this role."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When he first ran into her in the hall, did Joanne's boyfriend know that she hadn't gotten the role?

How do you think Joanne felt?

Control questions: In the story, what role did Joanne get?

What kind of role had she had the previous year?

What did her boyfriend say?

10. Joe was at the library. He found the book he wanted about hiking in the Grand Canyon and went up to the front counter to check it out. When he looked in his wallet, he discovered he had

left his library card at home. "I'm sorry," he said to the woman behind the counter. "I seem to have left my library card at home." "That's OK," she answered. "Tell me your name, and if we have you in the computer, you can check out the book just by showing me your driver's license."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When Joe went into the library, did he realize he didn't have his library card?

How do you think Joe felt?

Control questions: In the story, what book did Joe get at the library?

Was he going to be able to check it out?

11. Jean West, a manager in Abco Software Design, called a meeting for all of the staff. "I have something to tell you," she said. "John Morehouse, one of our accountants, is very sick with cancer and he's in the hospital." Everyone was quiet, absorbing the news, when Robert, a software engineer, arrived late. "Hey, I heard this great joke last night!" Robert said. "What did the terminally ill patient say to his doctor?" Jean said, "Okay, let's get down to business in the meeting."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When he came in, did Robert know that the accountant was sick with cancer?

How do you think Jean, the manager, felt?

Control questions: In the story, what did Jean, the manager, tell the people in the meeting?

Who arrived late to the meeting?

12. Mike, a nine-year-old boy, just started at a new school. He was in one of the stalls in the restroom at school. Joe and Peter, two other boys, came in and were standing at the sinks talking. Joe said, "You know that new guy in the class? His name's Mike. Doesn't he look weird? And he's so short!" Mike came out of the stall and Joe and Peter saw him. Peter said, "Oh hi, Mike! Are you going out to play football now?"

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When Joe was talking to Peter, did he know that Mike was in one of the stalls?

How do you think Mike felt?

Control questions: In the story, where was Mike while Joe and Peter were talking?

What did Joe say about Mike?

13. Kim's cousin, Scott, was coming to visit and Kim made an apple pie especially for him. After

dinner, she said, "I made a pie just for you. It's in the kitchen." "Mmmm," replied Scott, "It smells great! I love pies, except for apple, of course."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When he smelled the pie, did Scott know it was an apple pie?

How do you think Kim felt?

Control questions: In the story, what kind of pie did Kim make?

How did Kim and Scott know each other?

14. Jeanette bought her friend, Anne, a crystal bowl for a wedding gift. Anne had a big wedding and there were a lot of presents to keep track of. About a year later, Jeanette was over one night at Anne's for dinner. Jeanette dropped a wine bottle by accident on the crystal bowl and the bowl shattered. "I'm really sorry. I've broken the bowl," said Jeanette. "Don't worry," said Anne. "I never liked it anyway. Someone gave it to me for my wedding."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Anne remember that Jeannette had given her the bowl?

How do you think Jeanette felt?

Control questions: In the story, what did Jeanette give Anne for her wedding?

How did the bowl get broken?

15. At Fernhaven Elementary School, there was a story competition. Everyone was invited to enter. Several of the fifth graders did so. Christine, a fifth grader, loved the story she had entered in the competition. A few days later, the results of the competition were announced: Christine's story had not won anything and a classmate, Jake, had won first prize. The following day, Christine was sitting on a bench with Jake. They were looking at his first prize trophy. Jake said, "It was so easy to win that contest. All of the other stories in the competition were terrible." "Where are you going to put your trophy?" asked Christine.

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Jake know that Christine had entered a story in the contest?

How do you think Christine felt?

Control questions: In the story, who won the contest?

Did Christine's story win anything?

16. Tim was in a restaurant. He spilled some coffee on the floor by accident. "I'll get you another cup of coffee," said the waiter. The waiter was gone for a while. Jack was another customer in the restaurant, standing by the cashier waiting to pay. Tim went up to Jack and said, "I spilled coffee

over by my table. Can you mop it up?"

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Tim know that Jack was another customer?

How do you think Jack felt?

Control questions: In the story, why was Jack standing by the cashier?

What did Tim spill?

17. Eleanor was waiting at the bus stop. The bus was late and she had been standing there a long time. She was 65 and it made her tired to stand for so long. When the bus finally came, it was crowded and there were no seats left. She saw a neighbor, Paul, standing in the aisle of the bus. "Hello, Eleanor," he said. "Were you waiting there long?" "About 20 minutes," she replied. A young man who was sitting down got up. "Ma'am, would you like my seat?"

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When Eleanor got on the bus, did Paul know how long she had been waiting?

How do you think Eleanor felt?

Control questions: In the story, why was Eleanor waiting at the bus stop for 20 minutes?

Were there any seats available on the bus when she got on?

18. Roger had just started work at a new office. One day, in the coffee room, he was talking to a new friend, Andrew. "What does your wife do?" Andrew asked. "She's a lawyer," answered Roger. A few minutes later, Claire came into the coffee room looking irritated. "I just had the worst phone call," she told them. "Lawyers are all so arrogant and greedy. I can't stand them." "Do you want to come look over these reports?" Andrew asked Claire. "Not now," she replied, "I need my coffee."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Claire know that Roger’s wife was a lawyer?

How do you think Roger felt?

Control questions: In the story, what does Roger's wife do for a living?

Where were Roger and Andrew talking?

19. Richard bought a new car, a red Peugeot. A few weeks after he bought it, he backed it into his neighbor Ted's car, an old beat-up Volvo. His new car wasn’t damaged at all and he didn’t do much damage to Ted’s car either -- just a scratch in the paint above the wheel. Still, he went up and knocked on the door. When Ted answered, Richard said, "I'm really sorry. I've just put a small scratch on your car.” Ted looked at it and said, "Don't worry. It was only an accident."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

Did Richard know what his neighbor Ted's reaction would be?

How do you think Ted felt?

Control questions: In the story, what did Richard do to Ted's car?

How did Ted react?

20. Louise went to the butcher to buy some meat. It was crowded and noisy in the shop. She asked the butcher, "Do you have any free-range chickens?" He nodded and started to wrap up a roasted chicken for her. "Excuse me," she said, "I must not have spoken clearly. I asked if you had any free-range chickens." "Oh, sorry," the butcher said, "we're all out of them."

Did anyone say something they shouldn't have said or something awkward?

If yes, ask: Who said something they shouldn't have said or something awkward?

Why shouldn't he/she have said it or why was it awkward?

Why do you think he/she said it?

When he started wrapping up a chicken for Louise, did the butcher know that she wanted a free-range chicken?

How do you think Louise felt?

Control questions: In the story, where did Louise go?

Why did the butcher start to wrap up a roasted chicken for her?

Appendix B

The Life Experiences Survey (Sarason, Johnson, & Seigal, 1978).

Listed below are a number of events which can sometimes bring about change in the lives of those who experience them. The events listed on this survey may or may not have entailed a life change for you. Please check those events which you have experienced either in the past year, or since the age of eleven years. Be sure that all check marks are directly across from the items they correspond to. Also, if the event your experience did have an impact, please rate the extent of it accordingly on the scale presented next to the event as having a positive or negative impact on your life as follows: *extremely negative* (- 3), *moderately negative* (-2), *somewhat negative* (-1), *no impact* (0), *slightly positive* (+1), *moderately positive* (+2), *extremely positive* (+3).

If you have experienced any of these events within the past year, please indicate your responses using a black pen. If you have experienced any of these events since the age of eleven years please indicate your responses using a red pen.

Section 1

1. Marriage
2. Detention in jail or comparable institution
3. Death of spouse
4. Major changes in sleeping habits (much more or much less sleep)
5. Death of close family member :

   a. mother
   b. father
   c. brother
   d. sister
   e. grandmother
   f. grandfather
   g. other (specify)
6. Major changes in eating habits (much more or much less food intake)
7. Forclosure on mortgage or loan
8. Death of a close friend
9. Outstanding personal achievemnet
10. Minor law violations (traffic tickets, disturbing the peace, etc.)
11. *Male* : Wife / girlfriend's pregnancy
12. *Female* : Pregnancy
13. Changed work situation (different work responsibility, major change in working conditions, working hours, etc.)
14. New job
15. Serious illness or injury of close family member :
   a. father
   b. mother
   c. sister
   d. brother
   e. grandfather

f. grandmother

g. spouse

h. other (specify)

16. Sexual difficulties

17. Trouble with employer (in danger of losing job, being suspended, demoted, etc.)

18. Trouble with in-laws

19. Major change in financial status (a lot better of or a lot worse off0

20. Major change in closeness of family members (increased or decreased closeness)

21. Gaining a new family member (through birth, adoption, family member moving in, etc.)

22. Change of residence

23. Marital separation from mate (due to conflict)

24. Major change in church activities (increased or decreased attendance)

25. Marital reconciliation with mate

26. Major change in number of arguments with spouse (a lot more or a lot less arguments)

27. *Married male*: Change in wife's work outside the home (beginning work, ceasing work, changing to a new job, etc.)

28. *Married female*: Change in husband's work (loss of job, beginning new job, retirement, etc.)

29. Major change in usual type and/or amount of recreation

30. Borrowing more than $ 10,000 (buying home, business, etc.)

31. Borrowing less than $ 10,000 (buying car, TV, school loan, etc.)

32. Being fired from job

33. *Male*: Wife / girlfriend having abortion

34. *Female*: Having abortion

35. Major personal illness or injury

36. Major change in social activities,

e.g. parties, movies, visiting (increased or decreased participation)

37. Major change in living conditions of family (building new home,

remodeling, deterioration of home, neighborhood, etc.)

38. Divorce

39. Serious injury or illness of close friend

40. Retirement from work

41. Son or daughter leaving home (due to marriage , college, etc.)

42. Ending of formal schooling

43. Separation from spouse (due to work, travel, etc.)

44. Engagement

45. Breaking up with boyfriend / girlfriend

46. Leaving home for the first time

47. Reconciliation with boyfriend / girlfriend

Other recent experiences which have had an impact on your life. List and rate.

48. ---

49. ---

50. ---

Section 2 : Student Only

51. Beginning a new school experience at a higher academic level (college, graduate school, professional school, etc.)

52. Changing to a new school at same academic level (undergraduate, graduate, etc.)

53. Academic probation

54. Being dismissed from dormitory or other residence

55. Failing an important exam

56. Changing a major

57. Failing a course

58. Dropping a course

59. Joining a fraternity / sorority

60. Financial problems concerning school (in danger of not having sufficient money to continue)

Table 1

Descriptive Statistics for the Prefrontal Cortex PFC)Tasks for the Younger and Older Groups

	18 year olds		22 – 25 year olds	
	M	*SD*	*M*	*SD*
Dorsolateral PFC Tasks				
3-Back Task	.76	.08	.78	.07
SOPT	.85	.08	.91	.06
Ventromedial PFC Tasks				
Faux Pas Task	.85	.11	.97	.05
Iowa Gambling Task	.56	.08	.60	.09

Note. 3-Back Task = Mean proportion correct across four trials. *SOPT* = Mean proportion correct across three trials on the Self-Ordered Pointing Test. *Faux Pas Task* = Mean proportion correct from control and faux pas questions. *Iowa Gambling Task* = Proportion of cards chosen from the advantageous decks.

Table 2

Pearson Correlations among PFC Measures and Stress Variables with Age Partialed Out

	1	2	3	4	5	6	7	8	9	10	11	12
1. SOPT	--											
2. 3-back	.08	--										
3. FP	.20	-.22	--									
4. IGT	.36*	.24	-.04	--								
5. DlPfc	.71**	.76**	-.02	.40*	--							
6. VmPfc	.41*	.04	.63**	.75**	.30	--						
7. Pfc	.71**	.52*	.35*	.70**	.83**	.78**	--					
8. Lt-Py	.10	-.10	-.05	-.19	.00	-.18	-.11	--				
9. Lp-Py	-.01	.03	-.29	-.15	.01	-.31*	-.17	.59**	--			
10. Ln-Py	.13	-.14	.15	-.13	-.01	-.00	-.01	.81**	.01	--		
11. Lt-11	-.05	-.18	-.01	-.38*	-.16	-.31*	-.28*	.51*	.12	.54**	--	
12. Lp-11	-.28	-.31	-.09	-.35*	-.40*	-.33*	-.45*	.06	.04	.05	.60**	--
13. Ln-11	.20	.16	.06	-.24	.25	-.15	.08	.48*	.03	.57**	.69**	-.06

Notes. $^{*}p < .05$. $^{**}p < .01$. *SOPT* = Mean proportion correct across three trials on the Self-Ordered Pointing Test. *3-back* = Mean proportion correct across four trials. *FP* = Mean proportion correct from control and faux pas questions on the Faux Pas Task. *IGT* = Proportion of cards chosen from the advantageous decks during the Iowa Gambling Task. *DlPfc* = Composite measure of DLPFC consisting of mean *z*-scores for the DLPFC tasks. *VmPfc* = Composite measure of VMPFC consisting of mean *z*-scores for the VMPFC tasks.

Pfc = Composite measure of the PFC consisting of mean *z*-scores for the DLPFC and the VMPFC tasks. *Lt-Py* = LES Total – Past Year. *Lp-Py* = LES Positive – Past Year. *Ln-Py* = LES Negative – Past Year. *Lt-11* = LES Total – Since Age 11. *Lp-11* = LES Positive – Since Age 11. *Ln-11* = LES Negative – Since Age 11.

Table 3

Results of Hierarchical Regression Analyses Predicting Composite Standardized PFC Measures using Stress Measures

Predictor	R^2	*F* Change	*df*	*p*
1. LES Total - Past Year	.057	2.25	1, 37	.142
2. LES Positive - Past Year	.081	3.26	1, 37	.079
3. LES Negative - Past Year	.009	0.34	1, 37	.566
4. (LES Total- Past Year) [a]	.087	1.72	2, 36	.194
LES Positive - Past Year				
LES Negative -Past Year				
5. LES Total – Since Age 11	.005	.197	1, 37	.660
6. LES Positive - Since Age 11	.002	0.06	1, 37	.813
7. LES Negative- Since Age 11	.054	2.10	1, 37	.155
8. LES Total - Since Age 11	.091	1.17	3, 35	.335
LES Positive - Since Age 11				
LES Negative - Since Age 11				
9. LES Total - Past Year	.057	2.25	1, 37	.142
LES Total - Since Age 11	.077	0.76	1, 36	.389

10. LES Positive - Past Year	.081	3.26	1, 37	.079
LES Positive - Since Age 11	.086	0.21	1, 36	.650
11. LES Negative - Past Year	.009	0.34	1, 37	.566
LES Negative - Since Age 11	.109	4.06	1, 36	.052

Notes. [a] In Model 4, *LES Total – Past Year* was excluded from the analysis as it was redundant with the predictive power of *LES Negative – Past Year*. Key: *LES Total - Past year* = Total number of potentially stressful events experienced in the past year. *LES Positive - Past year* = Sum of the positive change scores, from events experienced in the past year. *LES Negative – Past year* = Sum of the negative change scores, from events experienced in the past year. *LES Total – Since Age 11* = Total number of potentially stressful events experienced since the age of eleven. *LES Positive - Since Age 11* = Sum of the positive change scores, from events experienced since the age of eleven. *LES Negative – Since Age 11* = Sum of the negative change scores, from events experienced since the age of eleven.