The Emotional Continuous Performance Task:
A Measure of “Hot” and “Cold” Executive Functions?

by

Andrea Schneider
BA, Wilfrid Laurier University, 2008

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Supervisory Committee

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Dr. Adam Krawitz, (Department of Psychology)
Supervisor

Dr. James B. Hale, (Department of Psychology)
Departmental Member

Abstract

Supervisory Committee
Dr. Adam Krawitz, Department of Psychology
Supervisor
Dr. James B. Hale, Department of Psychology
Departmental Member

Using neutral and emotional faces as stimuli, the Emotional Continuous Performance Task (EMO-CPT) was designed to measure both “cold” and “hot” executive functions. It was predicted that neutral stimuli would be associated with “cold” circuit functions such as sustained attention and response speed, while emotionally-laden EMO-CPT stimuli would be associated with “hot” circuit functions such as emotional judgement and response inhibition. Twenty-one male and 56 female university students (*M* = 21.57 years; *SD* = 3.15) completed the EMO-CPT, Counting Stroop (CS), Balloon Analogue Risk Task (BART), Behaviour Rating Inventory of Executive Function (BRIEF), and a demographic survey. The EMO-CPT consisted of 240 trials counterbalanced into 8 separate blocks of neutral, happy, and angry faces, with 1500ms and 3000ms stimulus intervals. Principle axis factor analysis with orthogonal (varimax) rotation revealed “Sustained/Speed” (SS; Eigenvalue = 4.26) and “Accuracy/Inhibition” (AI; Eigenvalue = 2.49) factors accounting for 48.75% of the total variance. The SS factor was modestly correlated with the BRIEF Metacognitive Index (MI; *r*=.25), and both the Sustained/Speed factor (*r*=.27) and the Accuracy/Inhibition factor (*r*=.25) were modestly correlated with the BRIEF Behavioural Regulation Index (BRI). As predicted, “cold” Counting Stroop reaction time variables were related to the Sustained/Speed factor (*r*’s .30 to .36), and the “hot” BART adjusted inflations SD were related to the Accuracy/Inhibition factor (*r* = -.22). Correlated with the CS and BRIEF MI, the Sustained/Speed factor appeared to tap “cold” dorsal circuit functions, while the Accuracy/Inhibition factor appeared to be related to “hot” ventral circuit functions.

Keywords: “hot” and “cold” executive function, frontal-subcortical circuits, emotion regulation, executive function, continuous performance task

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Chapter 1
Introduction

Self-control skills are essential for everyday adaptive human behaviour. Sustained attention, response inhibition, and regulation of emotion are integral components of these self-control skills, commonly globally referred to as “executive function” (EF). The frontal lobes are inextricably linked with EF, and their functioning is crucial for higher consciousness, releasing us from the restrictions of the present moment and freeing us to form goals, devise plans, weigh the consequences of multiple plans, and execute the most advantageous plans in the pursuit of these goals (Cummings & Miller, 2007; Luria, 1966). Thus, defined as the set of cognitive processes involved in self-control and the regulation of goal-oriented behaviour, “executive function” permits us to organize, plan, strategize, attend to and remember relevant information, maintain performance over time, and evaluate and change behaviour in an adaptive manner (Goldberg, 2001). EF is a defining feature of what it means to be human, and indeed, executive dysfunction often devastatingly impacts an individual’s quality of life in many domains, including their success at work, in social relationships, and ability to live independently (Goel, Grafman, Tajik, Gana, & Danto, 1997; Green, Kern, Braff, & Mintz, 2000).

Parsing out the main components of EF, and elucidating patterns of brain processing underlying these constituent parts can inform the neuropsychological literature on executive function in the “typical” brain (Hale & Fiorello, 2004). Further, determining patterns of performance indicative of dysfunction in each of these major subcomponents presents an unobtrusive, inexpensive, efficient, and effective method of diagnosis for a wide range of neuropsychiatric disorders associated with executive dysfunction. Thus, the development of measures of EF which are sensitive to the operation of functionally dissociable parts of the executive brain may ultimately enhance the identification, diagnosis, and effective treatment of many neuropsychiatric disorders. The current study details the development and validation of such a measure.

Limitations of a “g” approach to EF

EF has historically been globally defined, yet it comprises an extensive range of cognitive operations that may be only loosely connected (Ozonoff, 1997). Theorists have attempted to develop hierarchical models of EF with a single unifying factor linking all cognitive components to measure general functioning in a global approach reminiscent of Spearman’s *g* (Duncan et al., 1996). Indeed, the cognitive constructs of fluid ability, or novel problem solving, and measures of EF share a strong relationship (Decker, Hill, & Dean, 2007; de Frias, Dixon, and Strauss, 2006), and structural modeling studies linking cognitive decline with EF suggest that the constructs of EF and general intelligence share an uncanny resemblance when individual differences are taken into account (Salthouse, Atkinson, & Berish, 2003). However, intercorrelations amongst various executive tasks tend to be low, suggesting that the different tasks are measuring diverse, yet interrelated components, rather than a unified trait (Miyake et al., 2000).

As with all higher-level functions, EF is likely the product of a highly interconnected system involving the convergence of many different areas of the brain, to varying degrees, in a graded, task-dependant manner (Luria, 1973; Hale & Fiorello 2004; Goldberg, 2001). Thus, the nomothetic *g* approach to EF is functionally limited by the underlying assumption that it is a static and innate ability that can be collapsed and accurately represented by a single, overarching norm-referenced measure (Fiorello et al., 2007; Hale et al., 2007). The clinical utility of this uni-dimensional approach is questionable. Indeed, the individual component processes of EF are separable enough that individuals may show domain-specific impairment in isolation from other, intact executive abilities. For example, executive deficits in individuals with autism typically include planning, and mental flexibility, while inhibitory control remains relatively intact. In contrast, a person with attention-deficit/hyperactivity disorder (ADHD) may not have problems with planning or fluid reasoning, while displaying impairment in inhibitory control and emotional lability (Happé, Booth, Charlton, & Hughes, 2006; Hill, 2004).

When this wide variability in the behavioural manifestations of executive dysfunction is taken into account, the notion that one absolute measure could capture or account for this diversity becomes apparently absurd; as if one were attempting to capture a rainbow or spectrum of disorders with the black-and white brush of a nomothetic score. Indeed, any variability seen across an individual’s processing profile becomes obscured when scores across multiple domains of functioning are collapsed and averaged together (Fuchs, Hale, & Kearns, 2011). This may explain the low discriminant validity of traditional EF tasks; different clinical groups may show similarly low overall test scores for different reasons. For example, perseveration in an individual with obsessive compulsive disorder versus distractibility and disinhibition in an individual with ADHD may both lead to poor performance and a low score on a Go-No-Go task (Cummings & Miller, 2007). Until an executive ability is broken down into its constituent processing demands, the specific processing deficit leading to poor performance cannot be identified; only the existence of overall executive dysfunction is apparent. Thus, EF impairments as measured by traditional tasks appear to be quite non-specific, leading some researchers to criticize the measurement of EF.

Utility of a patterns of cognitive processing approach

To address the aforementioned issues with traditional tests of EF, many theorists advocate for a multi-component approach focused on individual differences, information processing, psychological processes, patterns of performance, and ecological validity (Hale & Fiorello 2004; Hale, Fiorello et al., 2007; Fuchs, Hale, & Kearns, 2011; Chan, Shum, Toulopoulou, & Chen, 2008). Greater specificity than the stimulus-input and response-output traditionally recognized by nomothetically-driven psychometric approaches benefits neuropsychological interpretation of executive dysfunction by offering a more qualitatively informative approach (Fiorello, Hale, Snyder, Forrest, Teodori, 2008). Indeed, advocates of idiographic assessment emphasize that accuracy in interpretation stems from inferences regarding psychological processes (Hale, & Fiorello, 2004).

When assessing individuals with the disorganized behaviour and cognition characteristic of executive dysfunction, it is critical to examine the processing demands unique to each task, and to explain variations in performance across different measures (Fiorello, Hale, Snyder, & Teodori, 2008; Hale, Wycoff, & Fiorello, 2010; Schneider, Parker, Crevier-Quintin, Kubas, & Hale, in press). A pattern-centered perspective presents a multidimensional approach; EF is seen as arising from various interdependent components (brain circuits) operating in synchrony towards adaptive goals (Burgess, 2000; Damasio, 1995; Luria, 1973; Norman & Shallice, 1986; Shallice, 1988; Stuss & Benson, 1986).

Unlike nomothetic approaches to EF which focus on overall level of performance and detection of global impairment, an idiographic neuropsychological perspective investigates patterns of processing strengths and weaknesses utilizing simple manipulations in tasks to allow for comparisons of specific measures and reveal inconsistencies in performance across different executive domains. This allows for an in-depth and meaningful interpretation of the individual's particular form of executive dysfunction. When an individual’s executive processing weaknesses are understood and their strengths appreciated, intervention can be tailored to their unique profile to create effective coping strategies (Hale & Fiorello, 2004). Neuropsychological perspectives offer a link between cognitive and neuroanatomical understandings of processing demands in a task-dependant manner.

Towards a neuropsychological circuit-driven perspective

Linking performance on measures of specific domains of EF to the functioning of particular brain circuits facilitates the neuropsychological analysis of executive dysfunction on an ideographic information-processing level (Burgess, 1997; Hale et al., 2009). This level of interpretation assists with the development of better tools for diagnosis and intervention for executive dysfunction (Hale, Kaufman, Naglieri, & Kavale, 2006). Instead of a global executive dysfunction or behavioural rating scale approach to identification of neuropsychiatric disorders, clinicians can use knowledge of circuit impairments and their related task performance deficits for differential diagnosis and treatment.

Although it is difficult to attribute complex cognitive processes to specific brain regions, several dissociable brain circuits have been implicated in distinct but overlapping functions. It has been proposed that sustained attention, response inhibition and emotion regulation are a product of the reciprocal interaction between, and within, the frontal lobes and subcortical regions, with specialized brain networks, known as the frontal-subcortical circuits (FSCs), each contributing to the executive control of behaviour in unique ways (Lichter & Cummings, 2001). These frontal-subcortical connections have been divided into five circuits, linking different frontal brain regions to the basal ganglia and thalamus (Alexander, DeLong, & Strick, 1986). Originating in the supplementary motor area, frontal eye field, dorsolateral prefrontal region, lateral orbitofrontal region and anterior cingulate, they have been respectively labelled as the “occulomotor”, “motor”, “dorsolateral”, “orbital”, and “cingulate” circuits (Lichter & Cummings, 2001; Tekin & Cummings, 2002). These circuits are comprised of afferent and efferent connections between frontal and subcortical regions, and transverse connections amongst the circuits themselves, enabling diffuse cortical regions to concertedly produce adaptive behaviour (Tekin & Cummings, 2002).

More specifically, the motor circuit is involved in motor control and coordination; the occulomotor circuit regulates visual attention and tracking; the cingulate circuit is proposed to facilitate processing speed and efficiency (Tekin & Cummings, 2002; Miller & Hale, 2008); the dorsolateral circuit is thought to regulate the “cold” executive abilities included in traditional definitions of EF (Rubia, 2011); and the orbitofrontal circuit is purported to mediate “hot” self-regulation and emotional control (Miller & Hale, 2008; Lichter & Cummings, 2001). Each of the five individual circuits forms a loop that begins in the prefrontal cortex and projects to the striatum (caudate, putamen, and ventral striatum) on to the globus pallidus, substantia nigra, and the thalamus before returning back to the frontal cortex (Figure 1).

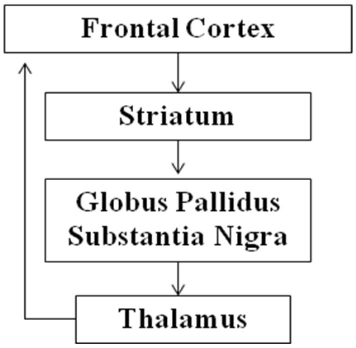

Figure 1. General connective structure of the frontal subcortical circuits (adapted from Tekin & Cummings, 2002).

Despite having these subcortical structures in common, the five circuits remain anatomically segregated from each other in separate loops with the dorsolateral frontal circuit projecting to the dorsolateral head of the caudate nucleus, the orbitofrontal circuit connecting to ventral striatal areas, and the anterior cingulate circuit linking to the nucleus accumbens and medial striatal areas of the caudate nucleus (Tekin & Cummings, 2002). These FSCs process information in parallel, however information is shared amongst the individual circuits through transverse connections. Thus they are considered to function as "open" circuits (Tekin & Cummings, 2002).

Abnormalities in frontal-subcortical circuitry are implicated in executive dysfunction, and these irregularities are indeed evident in most neuropsychiatric disorders, with research showing that impairments in different circuits leads to distinct disorders (Alexander, DeLong, & Strick, 1986; Heyder, Suchan, & Daum, 2004; Lichter & Cummings, 2001). The dorsolateral and orbitofrontal (ventromedial) circuits prove to be the most clinically relevant for executive dysfunction, and a theoretical bifurcation of the prefrontal cortex along dorsolateral and ventromedial circuits is increasingly common. Indeed, the dorsolateral-dorsal and orbital-ventral FSCs are most often associated with the changes in behaviour and cognition (EF) that accompany neuropsychiatric syndromes or brain injury (Tekin & Cummings, 2002), and the functional divide between these two circuits is so thorough, that Goldberg (2001) described the orbitofrontal syndrome as being "in many ways the opposite of the dorsolateral syndrome". These two major divisions of the FSCs are otherwise referred to as the "hot" ventromedial and "cold" dorsolateral circuits in reference to their function. Dorsal system "cold" executive functions and ventral system "hot" executive functions provide a clinically useful way of classifying the functional role of the FSCs in EF.

This loose parcellation of FSC function can facilitate the examination of executive dysfunction by revealing patterns of performance unique to specific neuropsychiatric disorders, and the neuroanatomical circuit dysfunction typical of each of these disorders (Tekin & Cummings, 2002). Damage to dorsolateral PFCs is marked by a flat affect, and apparent lack of "drive" created by dysfunction in traditional forms of EF including: sustained attention, working memory, planning, organization, monitoring, mental flexibility, evaluating, and changing task performance in relation to environmental demands (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Rubia, 2011). Thus, the "cold" dorsolateral circuits can be seen as involved in the control of the individual's external environment. These dorsal functions can be dissociated from "hot" executive control of an individual's internal socio-emotional environment. These "hot" executive functions are regulated by the orbital and ventral cingulate FSCs, which govern socially adaptive behaviour, self-control, regulation of emotion, response inhibition, and modulation of internal states (Borst, Thompson, & Kosslyn, 2011; Chan et al., 2008; Fellows & Farah, 2005; Kerr & Zelazo, 2004; Schoenbaum, Roesch, & Stalnaker, 2006). Indeed, orbitofrontal circuit damage leads to behavioural self-regulation problems in emotional and social contexts, evident in "personality" changes such as disinhibition, and emotional lability (Chow & Cummings, 2007). Consequently, the function of the "cold" dorsolateral and "hot" orbitofrontal FSCs as integrators of information from both the external sensory and internal limbic-emotional worlds and their role in attention, motivation, and inhibition, make them essential for an understanding of both average and disordered EF.

Attention and emotional regulation

A further problem arises in the form of ecological validity of tests of EF. Individuals with impairment in orbitofrontal FSCs may often show little or no detectable impairment on traditional neuropsychological tests of EF, perception, intelligence, memory, or language, despite experiencing debilitating impairment in their everyday social, vocational, and economic life functioning (Zillmer, Spiers, Culbertson, 2008). Their performance on tests of general intellectual function is in fact often superior, and they fail to show impairment on any formal test which would correspond with their difficulties in everyday life (Burgess, Veitch, Costello, & Shallice, 2000; Laiacona et al., 1989, Stuss et al., 2000). This includes tasks previously shown to be sensitive to frontal lobe dysfunction (e.g. card sorting tasks). Thus, a more in-depth and ecologically valid examination of the multifaceted impact of executive dysfunction is required for multiple executive domains of daily functioning.

The partition of EF into “hot” and “cold” circuits explains how many patients with a neuropsychiatric disorder or brain injury manage to perform within an average range on these traditional neuropsychological tests of EF (e.g. Wisconsin Card Sorting Test [WCST]) while experiencing significant and pervasive problems in everyday life. Impairments in different FSCs can cause different forms of executive dysfunction, and measuring an individual’s control over internal emotional states can prove to be quite difficult in controlled laboratory conditions with traditional paper-and-pencil tests. The ability to inhibit emotional reactions that are disadvantageous and filter incoming information that is irrelevant to the task at hand is essential for sustained attention. Further, the ability to regulate one’s internal emotional environment to behave appropriately in a social world and inhibit socially deleterious reactions is one of the most important determinants of overall life success. Thus, it is imperative that neuropsychological tasks be developed to effectively measure orbitofrontal forms of behavioural regulation and identify impairments in this neural circuitry.

To better appreciate the multifaceted relationship between traditional forms of EF and behavioural regulation of internal emotional states, emphasis must be placed on creating tasks that incorporate more complex and life-like demands (Chan et al., 2008). Tasks should be developed to simultaneously tap a number of executive domains to reveal the functioning of dorsolateral and orbitofrontal circuits and the patterns of performance indicative of dysfunction in either of these FSCs (Hale et. al., 2001). Such tasks may highlight qualitative differences across different domains of EF within and across individuals and neuropsychological disorders. Indeed, an ADHD meta-analysis by Dickstein et al. (2006) established that studies which measure multiple constructs tend to find more extensive patterns of hypofunction in children with ADHD than those which only include measures of response inhibition (Dickstein et al., 2006).

Measuring “hot” and “cold” EF

Research has led to the development of a large array of tests designed to measure the “cold” aspects of EF, and very few tasks sensitive to “hot” emotional regulation (e.g. the Iowa gambling task and its derivatives; Bechara et al., 1996; Elliott, Friston, & Dolan, 2000; O’Doherty, Kringelbach, Hornak, Andrews, & Rolls, 2001). Replicating the “messy” challenges of everyday life, and measuring the emotional control required to successfully navigate these obstacles is difficult under controlled experimental conditions. Most measures of EF assess only the emotionally-neutral forms of executive control (e.g. WCST, Tower of London, Stroop Task). Thus, the reciprocal relationship between EF and emotion is neglected in our understanding of attention and response inhibition. Further, there is a paucity of tests designed to simultaneously compare and contrast “hot” and “cold” EF, and the functioning of these circuits remains to be directly compared within a single task. Different tests use different modalities, stimuli, and scenarios, sacrificing psychometric integrity when “hot” and “cold” circuit functioning is compared utilizing different measures.

The development of a task capable of directly comparing the functioning of “hot” and “cold” circuits may help elucidate the convoluted relationship between these important components of everyday functioning. Adjusting the requirement for emotional control across conditions within one test would allow for a more direct comparison of “hot” and “cold” circuit functioning and a more thorough understanding of how these circuits interact. This would allow investigators to examine how control over internal emotional states impacts executive abilities such as sustained attention.

Thus, the endeavour of the current study was to modify a well-established test of “cold” EF to create what the researchers coined the “Emotional Continuous Performance Task” (EMO-CPT). Modified from a conventional Continuous Performance Test (CPT) paradigm, this task was designed to be the first measure of EF to tap both “cold” dorsolateral and “hot” orbitofrontal circuit functioning.

CPTs as Measures of FSC function

The CPT paradigm was developed in the 1950’s to detect brain damage and assess sustained attention (Rosvold et. al., 1956). The CPT is the most frequently used measure of attention and response inhibition for research and clinical practice (Riccio, Reynolds, Lowe & More, 2001), and is used to study a myriad of the conditions created by executive dysfunction, including: schizophrenia, attention-deficit hyperactivity disorder, affective disorder, tic disorder, conduct disorder, learning disabilities, and brain damage (Borgaro et al., 2003; Nichols & Wasbusch, 2004).The original task, the “CPT-X” (Rosvold et. al., 1956), involved a random sequence of letters shown to participants with an inter-stimulus interval of 920ms. Participants were asked to respond with a lever press every time the letter “X” appeared. In doing so, the participant had to sustain their attention and respond to the letter “X” while inhibiting this prepotent response when any other letter appeared.

Many modifications of the CPT have been created using varying target and non-target stimuli. Numbers (e.g. Gordon, 1983), pictures of objects or people (e.g., Anderson, Siegel, Fishc, & Wirt, 1969), words (e.g., Earle-Boyer, Serper, Davidson, & Harvey, 1991), colours of letters (Klee & Garfinkle, 1983), auditory stimuli (e.g. Earle-Boyer et al., 1991), and degraded visuals (Buchsbaum et al., 1990) have all been utilized as stimuli. Further, the frequency of the target stimuli has been manipulated to be relatively frequent or infrequent compared to the non-target stimuli (e.g., Beale, Matthew, Oliver, & Cornballis, 1987). The duration of the stimulus presentation is usually varied anywhere between 500ms and 1000ms (e.g., Chee, Logan, Lindsay, & Wachmsuth, 1989) and the inter-stimulus interval has been varied in many studies using shorter, longer, variable, or adaptive intervals based on participants’ performance (e.g., Girardi, et al., 1995; Rueckert & Grafman, 1996). Finally, distractor conditions (e.g., Crosby, 1972), feedback conditions (e.g., O’Dougherty, Nuechterlein, & Drew, 1984), and reinforcement conditions based on performance (e.g., Levy & Hobbes, 1988) have all been included in previous research.

CPTs have two types of errors in performance: *omission* errors are made when an individual fails to respond to a “go” trial, and are indicative of a lack of attention or alertness. Errors of c*ommission* are made when an individual responds to a “no go” trial and are indicative of impulsivity or poor response inhibition. Further, two subtypes of commission errors may exist with *fast* reaction time errors being associated with impulsivity and hyperactivity, and *slow* reaction time errors being associated with inattention (Halperin et al., 1988). Reaction time (latency to respond) is often reported as a measure of processing speed, decision making, and motor responding, which are all indicative of cognitive efficiency. The consistency or variability in an individual's performance over time, interpreted as a measure of sustained attention, is also measured by calculating the standard deviation of reaction times across blocks (Levin, Winston, et al., 1996). Indeed, impairments in "vigilance" or sustained attention as measured by variability in performance may be one of the most characteristic identifiable features in the performance of individuals with executive dysfunction causing inattention (e.g. ADHD; Huang-Pollock, Nigg, Halperin, 2006).

The CPT demonstrates sensitivity to dysfunction of the executive attentional system and is sensitive to attentional disturbance, but problematically lacks diagnostic specificity. Indeed, the performance of individuals with ADHD, anxiety, and depression, amongst many other neuropsychological conditions, may be indistinguishable on traditional CPTs (Riccio, Reynolds, & Lowe, 2001; Riccio & Reynolds, 2001). This lack of specificity may be due in part to the focus of traditional CPTs on measurement of "cold" FSCs and their inherent inability to detect impairment in "hot" circuits. In terms of general attentional control, "cold" PFCs are thought to be involved in selecting, sustaining, and orienting, and "hot" circuits in inhibitory control and filtering of attention (Fuster, 2002). Thus, it is hoped that adding an emotional component to a well-established measure of attention and response inhibition (the CPT) will provide a more accurate and precise overall evaluation of "hot" inhibitory control and "cold" attentional vigilance.

Practitioners need cost- and time-effective methods for determining the presence of executive dysfunction-based neuropsychiatric disorders, and the specific brain circuits involved in these disorders. If a convenient measure of "hot" and "cold" EF could differentiate between different FSC impairments, such a task could be used to enhance assessment, differential diagnosis and treatment planning. Therein lies the long-term motivation for developing the EMO-CPT task. The current investigation represents the first steps towards validating such a measure.

The current investigation

Facial expression is an essential part of human nonverbal communication of emotion from birth onward.We become familiar with facial affect at a very young age, making face-stimuli consistent with situations we navigate on a daily basis. The use of emotional faces as stimuli to tap “hot” FSCs is expected to represent a step in neuropsychological testing towards real-world forms of information processing. Utilizing emotional faces as stimuli to activate “hot circuits” also presents an elegant solution for working with young children and patients with impaired overall functioning (e.g. severe brain damage); populations who may otherwise be excluded from testing that includes complicated experimental task instructions (e.g. the Iowa Gambling Task, and the Theory of Mind Task). Further, utilizing faces as stimuli allows investigators to adjust the emotional valence of an experimental task to independently investigate the functioning of both “hot” and “cold” FSCs while keeping all other experimental variables constant.

The effects of emotion on selective attention are thought to be due to biased competition (Bradley et al., 2010; Desimone & Duncan 1995). A strong biological predisposition compels humans to focus on stimuli with emotional characteristics. Thus, an emotional stimulus may innately appear more salient and distinct than a neutral stimulus. This results in part from an interaction between bottom up and top down processing; environmental context, past experiences and prior knowledge, as well as emotional characteristics of the stimulus itself, create biased competition (Desimone & Duncan 1995; Damasio, 1998).

Viewing emotional faces has been shown to evoke similar emotional responses within the observer, with studies showing increases in self-reported emotion, heart rate, and galvanic skin response after viewing images of emotional faces (Wild, Erb, & Bartels, 2001). Further, the type of emotion presented has been shown to differentially affect heart rate, with relative increases in heart rate seen in response to sad and angry facial expressions and relative decreases observed in response to happy and disgusted facial expressions (Critchley et al., 2004). Interestingly, these increases in heart rate were predicted by the level of activity (as measured by fMRI) in a network of interconnected brain regions, including the amygdala, insula, anterior cingulate, and brainstem. This supports the idea that viewing images of emotional faces evokes similar emotions in the observer, on a mental, physiological, and neurological level, and that different types of emotions are differentially processed in the brain (Critchley et al., 2004).

Thus, the EMO-CPT was developed to include emotionally-charged (happy or angry) and emotionally-neutral male faces as stimuli in a series of trials in a NON-X-CPT paradigm (inhibit responding to target stimulus). This test was developed to have the emotionally-charged faces be extraneous to the main task required of a participant: to respond to faces with brown hair and inhibit responding to faces with blonde hair. It was expected that successfully performing this task would require the “cold” cognition (e.g. keeping task instructions in mind and inhibiting responding according to these instructions) of dorsal system circuits, regardless of the emotional valence of the faces. In contrast, it was expected that the “hot” emotion regulation of ventral system circuits would be required in addition to “cold” ventral cognition in order to perform successfully on emotionally charged trials (happy and angry conditions). Thus, the EMO-CPT was expected to tap “cold” circuits on neutral trials and both “hot” and “cold” circuits on emotionally-charged trials in a manner that is hoped to allow for the parsing apart of orbitofrontal vs. dorsolateral circuit function in a subtraction-type method. Thus, the current study investigated whether two factors (a “hot” and “cold” factor) would derive from data collected from a university undergraduate population.

The current investigation also endeavoured to evaluate the construct validity of the EMO-CPT by comparing correlations between performance on emotionally-neutral and emotionally-charged trials with pre-established direct and self-report measures of “hot” EF (Balloon Analogue Risk Task [BART; Rao et al. 2008]; Behavioral Rating Inventory of Executive Function [BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000] Behavioural Regulation Index [BRI]) and “cold” EF (Counting Stroop [CS; Bush et al,. 1998]; BRIEF Metacognitive Index [MI; Gioia, Isquith, Guy, & Kenworthy, 2000]). Specifically, this study examined whether performance on neutral EMO-CPT trials would correlate with the pre-established measures of “cold” EF and performance on emotional EMO-CPT trials would be associated with the pre-established measures of “hot” EF. Finally, the current study further investigated whether the distraction of emotionally charged faces in emotional trials resulted in changes in response speed and rates of error commission and omission (accuracy) relative to emotionally-neutral trials, and whether the type of emotion displayed (angry or happy) differentially effected performance.

Chapter 2
Methods

Participants

Participants included 56 female and 21 male university undergraduate students ranging in age from 18 to 39 years (*M* = 21.57; *SD* = 3.19). All data was collected in adherence with the ethical standards set forth by the University of Victoria (UVic) Human Research Ethics Board. Participants were required to be fluent in English, not be taking any psychotropic medications (e.g. stimulant medications), have normal or corrected to normal vision, and no reported history of severe brain injury or medical disorder affecting cognition. On average, participants had received 14.62 years of formal education (*SD*=1.23), with the majority of the participants being in their 3rd year of undergraduate studies (N=25), fewer participants in their 2nd year of university (N=21); 1st year (N=14); 4th year (N=14); and 5th year or higher (N=3). Participants had a mean grade point average of 5.92 (corresponding to a "B" letter grade) on a 9.0 scale (*SD* = 1.57). Sixty-nine participants were right handed and 8 left handed. Six participants reported that they had been diagnosed with a psychological disorder (depression, anxiety, or disgraphia). Sixteen participants reported sustaining a mild concussion and ten participants reported that they were currently taking a non-psychotropic medication (e.g. birth control, immune-suppressants, non-drowsy allergy medications). Fifty-five participants reported English as their first language, with fewer participants reporting Mandarin (N=17); Punjabi (N=2); Korean (N=1); Farsi (N=1); and Bosnian/Serbian (N=1) as their first language. Twelve participants responded "yes" when asked if they experiencing any extraordinary circumstances the day of testing (e.g., lack of sleep, illness, hunger). Reported reasons for this answer were carefully examined by the research team, and data from 13 participants experiencing extenuating circumstances which could impact their performance in the study were excluded from analysis (e.g. limited English proficiency, construction noise in the testing room, currently taking psychotropic medications, failure to fill out the demographic questionnaire), leaving the final reported sample of 77 participants from an original sample of 90.

Measures

Emotional Continuous Performance Task (EMO-CPT). The EMO-CPT consisted of one run of 240 trials written in and presented with E-Prime® computer software for Microsoft Windows® (Psychology Software Tools, Inc., Pittsburgh, PA; Schneider, Eschman, & Zuccolotto, 2002). Stimuli presented included the faces of 5 adult Caucasian males with happy, angry, or emotionally neutral facial expressions taken from the standardized MacBrain NimStim Emotional Face Stimuli Set (NimStim; see figure 2) available at www.macbrain.org. There were two levels of emotional intensity presented for each emotion: 50% emotional and 100% emotional, as defined by the NimStim.

Figure 2. Example showing the 100% angry, 50% angry, neutral, 50% happy, and 100% angry conditions in one of the non-target (brown haired) faces utilized in the EMO-CPT.

The image of the chosen target face was altered to have blonde hair, and the 4 remaining non-target faces had brown hair. Participants were asked to respond to faces with brown hair by pressing the spacebar on a computer keyboard, and to inhibit responding (avoid hitting the spacebar) to the face with blonde hair. Specifically, task instructions on the computer screen stated:

> In this task, you will see faces.
> When you see faces with brown hair,
> press the SPACEBAR:
> When you see a face with blonde hair,
> DO NOT press the SPACEBAR

The EMO-CPT took each participant approximately 9 minutes to complete, with 3 seconds of fixation at the beginning and end of the task. Participants first performed a practice block that consisted of 8 predetermined (e.g., nonrandom) trials, after receiving preliminary task instruction. Performance was observed during these practice trials by the investigator, and participants who committed many errors were asked whether they understood the task, and ran through the set of practice trials again. Once the participants reported they were comfortable with the task instructions, the investigator asked if they had questions prior to beginning the “real” task. All responses were made on the spacebar, and recorded by the E-Prime® software. Participants were instructed to keep their finger(s) on the spacebar throughout each run of trials.

The experimental run was organized into 8 blocks of trials consisting of either neutral (N), happy (H), or angry (A) faces (see *Figure 2*). The block order of NHNANHNA or NANHNANH was counterbalanced across subjects, with 20 neutral trials in each N block, and 40 trials in each happy and angry block. Non-target faces (with brown hair) made up 80% of each block; the remaining 20% of trials included the target (the blonde face). The trials occurred in immediate sequence and were long or short in duration with a stimulus presentation time of 1500 ms for 50% of trials and 3000 ms for the remaining 50% of trials. The order of stimulus presentation time was randomly determined by the E-Prime® software.

Dependant measures included accuracy (ACC) in responding, reaction time (RT), and variability in RT. RTs were recorded by the E-Prime® software and defined as time, in milliseconds, taken to respond by hitting the space bar after the onset of on-screen stimulus presentation. Standard deviations of these RTS were utilized as measures of variability in RT.

Counting Stroop (Bush et al., 1998). Developed specifically for use in fMRI studies, the Counting Stroop has become a standard attentional measure (Bush et al., 1998). Neuroimaging studies with the Colour Stroop and Counting Stroop show activation in the "cold" circuits of the dorsal system, specifically the dorsolateral prefrontal cortex, the anterior cingulate cortex and the posterior parietal cortex (Macdonald, Cohen, Stenger, & Carter, 2000; Zyseet, Muller, Lohrmann, & von Cramon, 2001). Thus, the Counting Stroop was seen as an ideal task to include as a pre-established measure of "cold" EF. The task requires participants to count the number of words (from 1-4) appearing on a computer screen, and respond by pressing the corresponding number on a keyboard. Participants were asked to use the middle and index fingers on each hand to respond, and to keep their fingers on the appropriate keys throughout each run of trails. The current study designated the 'z' key as representing 1 word, 'x' as 2 words, '.' as 3 words, and '/' as indicating 4 words. Specifically, the on-screen instructions stated:

> You will see sets of one to four identical words on the screen. Sometimes the words will be common animal names (bird, cat, dog or mouse) and sometimes they will be number words (one, two, three or four).
>
> You should report, by key press, the NUMBER of words in each set, regardless of what the words are.
>
> The labeled keys represent responses 1, 2, 3, and 4, from left to right. Use the index and middle fingers of each hand to respond.

The sets of words will change every 1.5 seconds. Answer as quickly as possible, but since getting the correct answer is important, do not sacrifice accuracy for speed.

Do not ‘blur your vision’ in an attempt to make the task easier - keep the words in sharp focus.

The Counting Stroop consisted of 2 runs of 160 trials lasting 1500 ms each. Each run was organized into 8 blocks of 20 trials. Neutral blocks consisted of neutral trials (pressing the number corresponding to the number of animal-words presented), and interference blocks consisted of congruent trials (pressing the number corresponding to the quantity of number-words presented when the number-words are *congruent* with the number of words on the screen) and incongruent trials (pressing the key corresponding to the quantity of number-words presented when the number-words are *incongruent* with the number of words on the screen). The neutral and interference blocks alternated, with the starting block type counterbalanced across participants and runs. During interference blocks, 25% of trials were congruent and 75% were incongruent. This breakdown in congruent and incongruent trials types resulted because the E-Prime® software was set up to randomly, but evenly, select number words (“one”, “two”, “three”, or “four”) and the quantity of words that would be presented on the screen (1-4 words).

Each run took approximately 4 minutes (plus 3 seconds of fixation at the beginning and end), with the entire task taking about 12 minutes to complete. All participants went through a neutral practice block of 20 animal-word trials followed immediately by an interference practice block of 20 number-word trials that took approximately 1 minute to complete (plus 3 seconds of fixation at the beginning and end). The accuracy of a participant’s performance on this practice block was reported on screen as percentage of correct trials immediately following the practice session. These results were reviewed by the experimenter with the participants, and participants who made many errors or who did not respond when required had the task requirements further explained to them. The starting block type was counterbalanced across subjects and runs. Each run took 4 minutes, with the entire task taking approximately 12 minutes. Dependant variables included RTs and accuracy in performance as measured by the E-Prime® software. RTs were defined as the amount of time in milliseconds taken to respond by hitting a designated number key (1, 2, 3, or 4) after the onset of on-screen stimulus presentation.

Balloon Analogue Risk Task (BART; Lejuez et al., 2002) . The BART was developed as a measure of risk-taking behaviour. Performance on the BART has been found to effectively measure an individual’s partiality for risk-taking behaviours such as sensation seeking and impulsivity (Lejuez et al., 2002), and traits indicating a neuropsychiatric disorder (Hunt, Hopko, Bare, Lejuez, & Robinson, 2005). A fMRI study with the BART found that the “hot” executive circuits were activated during this task, with regions of reward circuitry showing activation (Rao et al., 2008). Thus, the BART was seen as an ideal task to include as a pre-established measure of “hot” EF. Participants were told that the goal of this task was to raise as much “money” as they could. This computerized task required individuals to pump up (inflate) balloons by pressing a letter on the keyboard to inflate, with an incentive or reward (e.g. money) given for each pump. However, the balloon could explode with each pump, losing the individual all of their earnings associated with that balloon. To save earnings, participants had to decide to stop pumping up the balloon, and deposit the earnings in a bank by pressing a “COLLECT” key (Lejuez et al., 2002). The current study designated the “F” key as “INFLATE” and the “J” key as “COLLECT”, and asked participants to keep their index fingers of each hand on the appropriate keys throughout the run of trials. Specifically, the on-screen task instructions stated:

You're going to see 30 balloons, one after another, on the screen. For each balloon, you will press the key labeled "INFLATE" to pump up the balloon. Each key press pumps the balloon up a little more.

BUT remember, balloons pop if you pump them up too much. It is up to you to decide how much to pump up each balloon. Some of these balloons might pop after just one pump. Others might not pop until they fill almost the whole screen.

You earn MONEY for every pump. Each pump earns 5 cents. But if a balloon pops, you lose the money earned on that balloon. To keep the money from a balloon, stop pumping before it pops and press the key labeled "COLLECT".

Each time you collect money or pop a balloon, a new balloon will appear.

Your goal is to earn as much money as you can.

Press SPACEBAR to see what the task will look like...

With each inflation of the balloon, the reward increased by 5 cents, but the participant risked losing all of their earnings if the balloon popped. The balloon was equally likely to pop on any given trial, with the maximum number of trials being 128. The likelihood of the balloon popping thus increased with each passing trial. For example: on the first trial, the odds of the balloon popping were 1/128, on the second trial they became 1/127, and by the 127th trial they became 1/2. Dependent measures included: total earnings (in dollars), number of explosions, number of inflations (pumps), adjusted inflations, standard deviations of inflations and of adjusted inflations, and an F-score. The F-score investigated the adaptive functioning of individuals by examining adjustments in performance according to the previous trial. Specifically, this score revealed the amount of variance in inflations on a trial that could be explained based on the outcome (participant decided to collect or balloon exploded) of the previous trial. Adjusted inflations measured the average number of pumps participants chose, with trials where the balloon popped being excluded. These trials were excluded to create a measure which was representative of a participant’s decision making. Since balloon pops were randomly selected by the E-Prime® software, trials where the balloon popped were not indicative of the choice or risk-taking behaviour of the individual.

With regards to total earnings, cautious individuals might not have many balloon pops, but they may not get as many earnings. High risk-takers may not get as many earnings either, as they may inflate the balloons too many times, resulting in many popped balloons and lost earnings. Thus, there was a cost-benefit ratio that participants had to consider each time they chose to inflate a balloon. Participants received instructions regarding the BART before performing the task. No practice trials existed, and the entire task was accomplished in 1 run consisting of 30 balloons. The duration of the task was entirely dependent on the participant, with an average participant taking approximately 5 minutes.

Behaviour Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000). The BRIEF is a self-report multidimensional behaviour rating scale designed to assess a person's perception of his/her own EF. It measures behavioural manifestations of executive dysfunction, and thus can be used to assess a broad range of neuropsychiatric disorders (e.g. learning and attentional disorders, traumatic brain injury, depression, and pervasive developmental disorders). The BRIEF includes 8 subscale measures that tap into different aspects of EF: behavioural inhibition, shifting from one situation to another, modulating emotional responses, initiating tasks or activities, holding and using information (i.e., working memory), managing current and future tasks (i.e., plan/organize), organizing, and monitoring behaviour. Three global indices are calculated: the Behavioural Regulation (BRI) and Metacognition (MI) indices, and an overall Global Executive Composite (GEC) score. The BRI incorporates the Inhibit, Shift, Emotional, and Self-Monitor subscales and is thought to tap "hot" orbitofrontal FSC function. The MI is comprised of the Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization subscales, and is thought to tap “cold” dorsolateral FSC function, and the GEC incorporates all sub-scales to give an overall rating of EF (Gioia et al., 2000).

Procedure

Participants were recruited using the online UVic SONA system, and received bonus credit towards their final grade in a UVic Psychology course of their choice as compensation. Experiments took place on weekdays and participants arrived at times they had scheduled throughout the day from 9:00 AM to 6:00 PM. Each session lasted approximately 50 minutes and involved one participant and one experimenter in a designated 10 by 10 foot laboratory space (a quiet windowless lab room free from visual or auditory distractions) in the UVic Psychology Department. The room contained two desks: the first functioned as a station for paper-and-pencil testing, and the second desk supported a standard PC desktop computer with a 22” monitor loaded with software to run the 3 computer-administered tasks. All sessions were run by one of two trained undergraduate research assistants or the graduate student principle investigator, under the supervision and guidance of two faculty members of the UVic Psychology Department.

Upon arrival, each participant was provided with and read a consent form which included the general purpose of the study, ethical considerations, and their rights as a participant (see Appendix A). Following a script with specific instructions (see Appendix B), the experimenter sat the participant in a non-rolling chair at the computer desk, facing the desktop computer, with their face approximately 60 cm from the screen. Participants were then guided by the experimenter through the EMO-CPT, followed by the Counting Stroop, and the BART. After completing the three computer tasks, participants moved to the paper-and-pencil testing desk, and asked to fill out the BRIEF rating scale and a short demographic survey developed by the investigators (see Appendix C). Identifying data were not connected with these forms, and participants were identified by research participant number only. Following data collection, a debriefing form was read to each participant (see Appendix D) to explain the purpose of the investigation and the participant was prompted to ask the experimenter any questions that they had and thanked for their time.

Analysis

Means and standard deviations of general demographic information reported on the demographic questionnaires were calculated. For the EMO-CPT, for each participant, for each relevant condition, accuracy was calculated as the proportion of trials with a correct response, go trial RT means and standard deviations were calculated from correct trials only, and stop trial RT means and standard deviations were calculated from incorrect trials only. Group-level minimum and maximum scores, means, and standard deviations were then calculated from these values for the 12 EMO-CPT performance variables of interest: accuracy, RTs, and standard deviations of RTs on go and stop trials, and short and long trials, across neutral, happy, and angry face stimuli. Significant differences in performance across the 12 variables of interest were investigated with repeated-measures Analyses of Variance (ANOVAs). A 2x3x2 Repeated Measures ANOVA of accuracy across go and stop, neutral, happy, and angry, and long and short stimulus presentation time conditions was conducted to examine any interactions in accuracy across conditions. Commission errors on no-go trials were utilized as a measure of behavioral inhibition and emotional modulation of this inhibition. A 3x2 repeated-measures ANOVA was conducted for reaction time across neutral, happy, and angry trials across long and short stimulus presentation times (on go trials only) to examine any interactions in RTs across conditions. Commission errors on stop trials were meant to be utilized as the primary measure of behavioral inhibition on the task. However, reaction times of stop trials were not included in this analysis, since reaction times were only obtained for the few trials in which the participant had made an error by pressing the spacebar on a no-go trial.

Within-task correlations were explored for the EMO-CPT variables. Exploratory principle axis factor analysis with varimax rotation and Kaiser normalization was conducted with data from the 12 EMO-CPT variables of interest to reveal the factors that accounted for the most variance in performance. Factor loadings of each of the 12 EMO-CPT variables on the factors revealed were also investigated to characterize each factor. The factors revealed were then treated as unique indices and Pearson correlations were conducted to analyze the relationship (concurrent validity) between scores on these two indices and performance on the BRIEF subscales (Inhibit, Shift, Emotional, Self-monitor, BRI, Initiate, Working Memory, Plan/Organize, Task Monitor, Organization, MI, GEC,), BART (adjusted inflations, SD of adjusted inflations, and F score), and Counting Stroop (accuracy, reaction times, and SD of reaction times across neutral animal, congruent number, and incongruent number words trials; differences in accuracy between neutral and congruent trials, incongruent and neutral trials, and incongruent and congruent trials; differences in RT between neutral and congruent trials, incongruent and neutral trials, and incongruent and congruent trials).

Chapter 3
Results

EMO-CPT

Characteristics of the outcome scores of interest from the EMO-CPT, Counting Stroop, BART, and BRIEF were investigated by calculating descriptive statistics (see Table 1).

Table 1.

Descriptive Statistics of EMO-CPT (N=77)

	Minimum	Maximum	Mean	*SD*
Accuracy Go	.96	1.00	.99	.01
Accuracy Stop	.70	1.00	.95	.05
Accuracy Go Short	.95	1.00	.99	.01
Accuracy Go Long	.95	1.00	.99	.01
Accuracy Go Neutral	.93	1.00	.99	.01
Accuracy Go Happy	.93	1.00	.99	.01
Accuracy Go Angry	.93	1.00	1.00	.01
Accuracy Stop Short	.65	1.00	.95	.6
Accuracy Stop Long	.72	1.00	.94	.07
Accuracy Stop Neutral	.71	1.00	.95	.07
Accuracy Stop Happy	.72	1.00	.95	.06
Accuracy Stop Angry	.64	1.00	.94	.08
Reaction Time Go	398.47	789.04	581.00	81.17
Reaction Time Stop	232.50	1633.50	447.47	180.04
Reaction Time *SD* Go	80.99	497.08	174.03	74.95
Reaction Time Go Short	401.35	816.54	590.86	86.07

Reaction Time Go Long	396.07	781.15	569.77	79.03
Reaction Time *SD* Go Short	65.30	519.02	177.60	83.11
Reaction Time *SD* Go Long	65.26	488.22	162.50	83.71
Reaction Time Go Neutral	407.82	761.53	580.39	79.23
Reaction Time Go Happy	398.76	809.04	580.86	81.86
Reaction Time Go Angry	389.18	820.90	582.45	94.62
Reaction Time *SD* Go Neutral	67.44	477.28	173.39	95.32
Reaction Time *SD* Go Happy	61.02	552.20	168.26	84.55
Reaction Time *SD* Go Angry	55.35	438.79	156.71	91.59
Reaction Time Go Happy-Neutral	-77.03	75.48	.48	37.64
Reaction Time Go Angry-Neutral	-160.52	101.73	2.06	48.54

Note: Reaction times measured in milliseconds. *SD*=Standard deviation

Accuracy

Differences in accuracy across conditions were examined with a 2x3x2 (Trial Type [go, stop] x Emotion [N, H, A] x Presentation Time [fast, slow]) repeated measures analysis of variance (ANOVA). This ANOVA revealed only a significant main effect of trial type, *F*(1, 76)=61.03, *p*<.001, with average accuracy on stop trials being slightly lower and variation in performance (*SD*) being somewhat higher than on Go trials. A significant main effect was not found for emotion or presentation time, nor was there a significant interaction found between trial type and emotion, trial type and presentation time, emotion and presentation time or trial type, emotion, and presentation time.

Reaction time

Differences in RTs on go trials were investigated with a 3x2 (Emotion [N, H,A] x Presentation Time [fast, slow]) repeated measures ANOVA. A significant main effect was found only for presentation time *F*(1,76)=23.23, *p*<.001 with reaction times being smaller on long trials than on short trials (see Figure 3). A significant main effect was not found for emotion or for the interaction between emotion and presentation time.

Average reaction time on stop trials was shorter than on go trials. However, average reaction time on stop trials was calculated from the few instances in which participants made the error of responding to stop trials. By necessity, fewer trials were included in the calculation of average reaction time on stop trials than on go trials. Thus, conclusions drawn from comparisons between these two types of trials were limited.

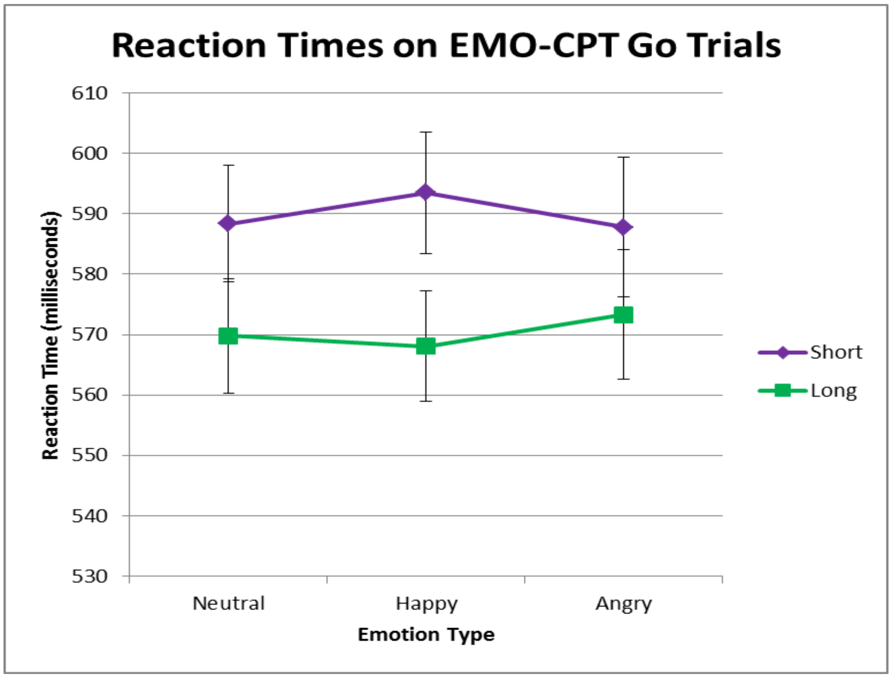

Figure 3. Reaction times on the EMO-CPT go trials across stimulus presentation time (1.5 seconds or 3 seconds) and emotion (N, H, or A). Error bars indicate standard error of the means (SEM).

A score was created to more directly compare the emotional component of the two emotional target categories (H and A) by removing variability that was due to the underlying cognitive component of the EMO-CPT task. This "difference score" was calculated by subtracting the RT of each subject on neutral trials from their RT on happy (H-N) or angry (A-N) trials. A paired samples t-test was conducted to compare these difference scores of RTs across happy and angry conditions. No significant difference was found between these "difference scores" across H-N (M=0.48, SD=27.64) and A–N (M=2.06, SD=48.54) trials, t(-.76)= -0.31, p=.758.

Variability in Reaction Time

Differences in SDs of RTs across go trials were investigated with a 3x2 (Emotion [N, H,A] x Presentation Time [fast, slow]) repeated measures ANOVA. Interestingly, the interaction between emotion and presentation time approached significance *F*(2,152)=2.87, *p*=.06 (see Figure 4). However, no significant main effects were found for emotion or presentation time.

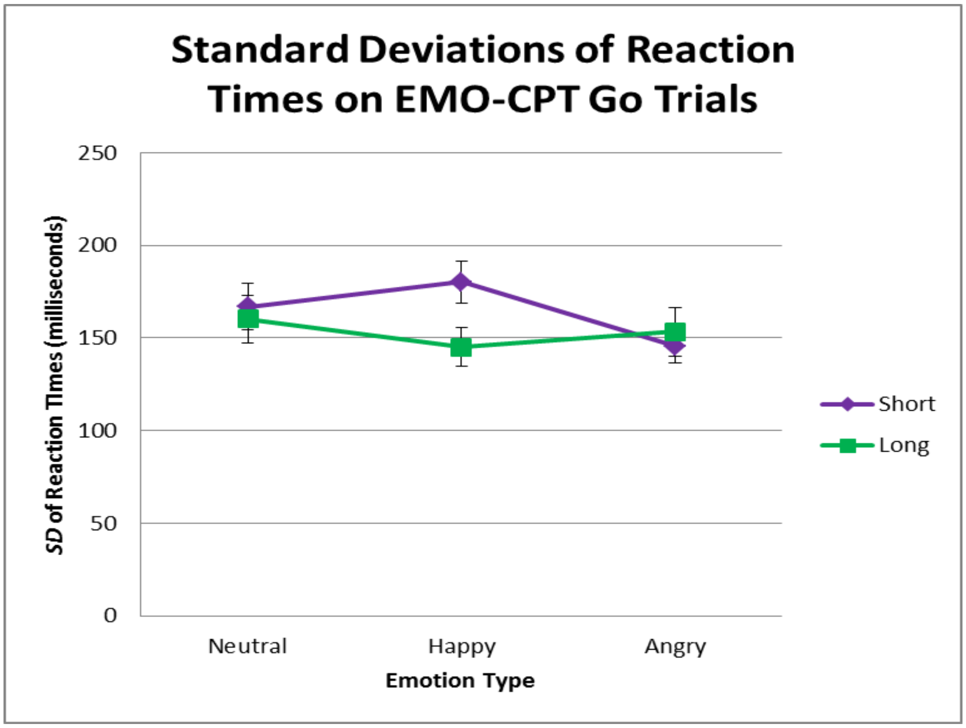

Figure 4. Standard deviations of reactions times on EMO-CPT go trials, across stimulus presentation time (1.5 seconds or 3 seconds) and emotion type (N, H, or A). Error bars indicate standard error of the means (SEM). *Note. SD*=Standard Deviation.

Internal Validity

Weak to moderate positive correlations (*r*'s .22 to .31) were found between accuracy on all go trials (N, H, and A; see Table 2). Moderate negative correlations were found between accuracy and both reaction time (*r*'s -.24 to -.44) and reaction time *SD* (*r*'s -.19 to -.46) on all go trial emotion types (N, H, and A). Strong correlations were found amongst RTs on all three go trial emotion types (*r*'s .86 to .89), and these go trial RTs were moderately positively correlated with reaction time *SD*s for all go trial emotion types (*r*'s .21 to .45) . Moderate positive correlations were found amongst reaction time *SD*s for all three go trial emotion types (*r*'s .43 to .57).

Table 2.

Correlations between Accuracy, Reaction Time, and Reaction Time Standard Deviations on the EMO-CPT (N=77)

	ACC Go Neutral	ACC Go Happy	ACC Go Angry	RT Go Neutral	RT Go Happy	RT Go Angry	RT *SD* Go Neutral	RT *SD* Go Happy	RT *SD* Go Angry
ACC Go Neutral	-	__.31**__	.22	__-.35**__	__-.34**__	__-.37**__	__-.28*__	__-.29**__	__-.27*__
ACC Go Happy		-	__.27*__	__-.31**__	__-.44**__	__-.30**__	__-.26*__	__-.46**__	-.19
ACC Go Angry			-	__-.35**__	__-.24*__	__-.32**__	__-.35**__	-.22	__-.26*__
RT Go Neutral				-	__.89**__	__.86**__	__.43**__	__.37**__	__.30**__
RT Go Happy					-	__.88**__	__.24*__	__.44**__	__.30**__
RT Go Angry						-	.21	__.38**__	__.45**__
RT *SD* Go Neutral							-	__.53**__	__.43**__
RT *SD* Go Happy								-	__.57**__
RT *SD* Go Angry									-

Note. ACC = Accuracy; RT = Reaction Time; *SD*=Standard Deviation. *p<.05, **p<.01

Factor Analysis

An exploratory principle axis factor analysis was conducted on the 12 items with orthogonal rotation (varimax). The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis, KMO= .72 (‘good’ according to Field, 2009). Bartlet’s Test of Sphericity $\chi^2(66)=513.93$, $p<.001$, indicated that correlations between items were sufficiently large.

An initial analysis was run to obtain eigenvalues for each component in the data. Two components had eigenvalues over Kaiser’s criterion of 1 and in combination explained 48.7% of the variance (see Table 3). The scree plot was quite clear and showed an inflexion that would justify retaining only the first 2 components. Table 4 shows the factor loadings after rotation. The clustering of items onto factors suggested that factor 1 represented a “Sustained/Speed” factor (Eigenvalue = 4.26) loading positively on go trial accuracies, and negatively on go trial reaction times and go trial reaction time standard deviations, and factor 2 represented an “Accuracy/Inhibition” factor (Eigenvalue = 2.47) loading positively on stop trial accuracies and go trial reaction times.

Table 3.

Eigenvalues associated with each linear component before extraction, after extraction, and after rotation (N=77)

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings	
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance
1	4.26	35.46	35.46	3.91	32.56	32.56	3.44	28.70
2	2.47	20.56	56.04	1.92	16.01	48.57	2.38	19.86
3	.97	8.05	64.10					
4	.87	7.28	71.38					
5	.84	6.98	78.36					
6	.65	5.40	83.76					
7	.61	5.09	88.84					
8	.48	3.97	92.81					
9	.42	3.55	96.36					
10	.31	2.59	98.94					
11	.07	.60	99.54					
12	.06	.48	100.00					

Table 4.

Factor Loadings for Exploratory Factor Analysis with Varimax Rotation of EMO-CPT Performance Variables of Interest

	Sustained/Speed	Accuracy/Inhibition
ACC Go Neutral	**.49**	.01
ACC Go Happy	**.51**	-.00
ACC Go Angry	**.41**	-.06
ACC Stop Neutral	.04	**.66**
ACC Stop Happy	.08	**.69**
ACC Stop Angry	.14	**.57**
RT Go Neutral	**-.71**	**.60**
RT Go Happy	**-.69**	**.61**
RT Go Angry	**-.69**	**.59**
RT *SD* Go Neutral	**-.62**	-.18
RT *SD* Go Happy	**-.76**	-.18
RT *SD* Go Angry	**-.59**	-.06

Note. Factor loadings > .40 are in boldface. ACC = Accuracy; RT = Reaction Time; *SD*=Standard deviation.

Counting Stroop

The Counting Stroop incongruent trials had less accuracy and more errors than the neutral or congruent trials (see Table 5). Mean RTs were similar across conditions. Mean RTs and RT *SD*s were highest on incongruent trials.

BART

The BART had a wide range of Earnings, balloon Explosions, and Inflations across participants (see Table 6). The Adjusted Inflations and Adjusted Inflations *SD* both had a wide range, showing variance across participant performance.

BRIEF

The BRIEF Behavioural Rating Index, Metacognitive Index and Global Executive Composite all had a wide range of scores. No participants scored over the threshold on the Infrequency or Inconsistency sub-scales that would suggest false or dishonest reporting.

Table 5.

Descriptive Statistics for Counting Stroop (N = 77)

	Mean	SD
ACC Neutral	.97	.02
ACC Congruent	.98	.27
ACC Incongruent	.94	.04
ACC Incongruent-Congruent	-.04	.04
RT Neutral	678.78	71.09
RT Congruent	676.78	75.04
RT Incongruent	739.13	80.06
RT *SD* Neutral	129.85	27.82
RT *SD* Congruent	140.48	41.96
RT *SD* Incongruent	155.34	30.88
RT Incongruent-Congruent	62.35	31.23

Note: Reaction times measured in milliseconds. ACC=Accuracy; RT=Reaction time; *SD*=Standard deviation.

Table 6.

Descriptive Statistics for BART (N=77)

	Minimum	Maximum	M	SD
Earnings	10.80	60.90	35.75	9.85
Explosions	2	25	10.65	4.43
Inflations	8.83	59.53	34.06	10.96
Inflations *SD*	4.22	38.88	19.11	7.10
Adjusted inflations	9.00	74.00	39.52	14.46
Adjusted inflations *SD*	1.77	34.82	16.35	6.65
F-Score	.00	25.36	3.58	4.87

Note: Earnings are in dollars. *SD*=Standard deviation

Table 7.

Descriptive Statistics for BRIEF (N=78)

	Mean	*SD*
Inhibit	13.25	2.82
Shift	10.03	2.55
Emotional	15.87	4.04
Self-Monitor	8.88	2.05
Behavioural Rating Index	48.03	8.88
Initiate	12.84	2.98
Working Memory	12.36	2.10
Plan/Organize	15.08	3.40
Task Monitor	10.35	1.96
Organization	12.61	3.43
Metacognitive Index	63.25	12.23
Global Executive Composite	111.27	19.50
Negativity	.22	.70
Infrequency	.17	.41
Inconsistency	3.34	1.88

Concurrent Validity

Correlations were examined between the Sustained/Speed factor and Accuracy/Inhibition factor and measures on the BRIEF, BART and CS to investigate the concurrent validity of the EMO-CPT. The Sustained/Speed factor correlated significantly with the BRIEF BRI, MI and

GEC, and with more of the subscale measures from the MI (Initiate, Working Memory, Plan/Organize) that from the BRI (Self-Monitor). This factor also correlated significantly with neutral, congruent, and incongruent RTs, and congruent and incongruent RT SDs on the CS.

The Accuracy/Inhibition Factor correlated significantly with the BRIEF BRI, two subscales of the BRI (Inhibit, and Self-Monitor), accuracy on congruent, and incongruent trials of the CS, and the difference score for incongruent-neutral accuracies on the CS.

Table 8.

Correlations Between the Sustained/Speed Factor and Accuracy/Inhibition Factor and Pre-Established Measures of "Cold" and "Hot" EF.

	Sustained/Speed	Accuracy/Inhibition
BRIEF Inhibit	.13	-.23*
BRIEF Shift	.21	-.19
BRIEF Emotional	.21	-.13
BRIEF Self- Monitor	.30**	-.25*
BRIEF BRI	.27**	-.25*
BRIEF Initiate	.25*	-.06
BRIEF Working Memory	.25*	-.07
BRIEF Plan/Organize	.29*	-.09
BRIEF Task Monitor	.22	-.14
BRIEF Organization	.05	-.15
BRIEF MI	.25*	-.12
BRIEF GEC	.28*	-.19
BART Adjusted inflations	.01	-.03
BART Adjusted Inflations *SD*	.10	-.22
BART F Score	-.16	-.01
CS ACC Neutral	-.12	.25*
CS ACC Congruent	-.16	.25*
CS AC Incongruent	-.16	.45*
CS RT Neutral	.34**	.18
CS RT Congruent	.36**	.18

CS RT Incongruent	.30**	.12
CS RT *SD* Neutral	.21	-.01
CS RT *SD* Congruent	.24*	-.10
CS RT *SD* Incongruent	.24*	-.12
CS ACC Neutral-Congruent	.04	-.02
CS ACC Incongruent-Neutral	-.11	.26*
CS ACC Incongruent-Congruent	-.05	.18
CS RT Neutral-Congruent	-.08	-.02
CS RT Incongruent-Neutral	-.01	-.10
CS RT Incongruent-Congruent	-.10	-.13

Note: Reaction times measured in milliseconds. ACC=Accuracy; RT=Reaction time; *SD*=Standard deviation. *p<.05, **p<.01

Correlations were investigated between EMO-CPT variables of interest and the BRIEF, BART, and CS (see Table 9). Accuracy on stop trials of the EMO-CPT was found to be significantly correlated with scores on the BRIEF BRI, *SD*s of the adjusted inflations score on the BART, and a difference score that compared accuracy on the CS on incongruent and congruent trial types. This score was created to better parse out the cognitive control portions of the CS task, and it was created by subtracting accuracy on congruent trials from accuracy on incongruent trials on the CS. This difference score was also found to be correlated with accuracy on neutral stop trials. Interestingly, this same CS difference score correlated significantly with the BRIEF MI index (r=-.27, n=77, p<.05). Further, a difference score subtracting RTs on neutral go trials from those on happy go trials (H-N) was significantly correlated with the BRIEF BRI. Finally, a difference score subtracting RTs on angry go trials from neutral go trials (A-N) was significantly correlated with a difference score that compared RTs on the CS on incongruent and congruent trial types.

Table 9.

Correlations between EMO-CPT Variables and Measures on the BRIEF, BART, and CS

	ACC Stop	ACC Stop Neutral	ACC Stop Happy-Neutral	ACC Stop Angry-Neutral	RT Go	RT Go Neutral	RT Go Happy-Neutral	RT Go Angry-Neutral
BRIEF BRI	**-.24***	-.15	-.06	-.08	.01	.07	**-.25***	.01
BRIEF MI	-.14	-.04	-.09	-.12	.08	.12	.16	-.02
BRIEF GEC	-.19	-.09	-.08	-.11	.06	.11	-.21	-.01
BART Adjusted Inflations	-.14	-.06	-.07	-.07	.01	.01	-.04	.09
BART Adjusted Inflations *SD*	**-.25***	-.18	-.03	-.06	-.05	-.05	-.03	.04
BART F-Score	.04	.00	.01	.09	-.13	-.12	.01	-.13
CS ACC Incongruent-Congruent	**.24***	**.30***	-.14	-.12	.05	.06	.01	-.07
CS RT Incongruent-Congruent	-.14	-.14	-.01	.10	-.14	-.21	.09	**.29***

Chapter 4
Discussion

The Current Findings

It was expected that two factors representing the functioning of "hot" and "cold" circuits would derive from the EMO-CPT data collected from a university undergraduate population. Indeed, exploratory principle axis factor analysis with orthogonal rotation (varimax) confirmed a 2 factor solution explaining 48.7% of the variance (see Table 10 for a summary of findings). The first factor was found to load negatively with RT and RT variability on go trials, and positively with accuracy on go trials, leading the investigators to label it as a "Sustained/Speed" factor. These loadings suggest that participants who had shorter reaction times and less variability in their reaction times were also more accurate. This first finding was unexpected, as a speed/accuracy trade-off had been predicted where longer reaction times would allow for more caution (inhibition) in responding, presumably leading to more accurate performance. Indeed, an inverse correlation between commission errors and RT is typically found with the closely related go/no go task, and a study with an emotional go/no go paradigm found this trade-off using emotional faces from the same NimStim set utilized in the current investigation (Shulz et al., 2007). This finding could be indicative of overall inattention amongst some participants. Slow reaction times, and greater reaction time variability, combined with greater errors are indeed typically associated with inattention (Halperin et al., 1988; Halperin, Wolf, Greenblatt, & Young, 1991). This pattern of performance may have been symptomatic of the relative ease with which the average young adult undergraduate student performed the EMO-CPT task; some participants may have found the task relatively simple and become quickly disinterested and distracted.

Greater standard deviations in reaction times were predicted to be connected with less accurate performance, as inconsistency in RTs has been connected with inattention, or impairments in “vigilance” of sustained attention (Huang-Pollock, Nigg, Halperin, 2006). This suggests that high-performing participants were able to vigilantly stay on task, and thus responded accurately, quickly, and with consistent reaction times, and low-performers lacked this vigilance in sustained attention, and thus responded slowly, inaccurately, and with inconsistent reaction times.

Accuracy on stop trials and RT variables on go trials were found to load positively on factor 2, thus, it was labelled as an “Accuracy/Inhibition” factor. These loadings suggest that participants who were slower on go trials were also better at inhibiting on stop trials. This relationship was expected, as the “Accuracy/Inhibition” factor was predicted to act as an index of a participant’s overall cautiousness in responding. Thus, while slower responding on go trials predicted higher rates of omission errors, it also predicted lower rates of commission errors, and vice versa. This differential relationship between reaction times and errors of commission and omission testifies to the independence of the two factors revealed in this study; vigilance in attention does not equate with cautiousness in responding. This partition of attentiveness and impulsivity aligns well with the hypothesized brain-based division of “hot” and “cold” circuit functioning. It further explains how damage to, or dysfunction in, different parts of the FSCs may lead to problems with disinhibition in an individual who retains the ability to sustain attention (e.g. ADHD predominantly Hyperactive-Impulsive subtype), or inattentiveness in an individual who does not experience problems with inhibition (e.g. ADHD Primarily Inattentive subtype). Interestingly, a study with childhood closed head injury found that these two domains of cognitive function had different outcome predictors. Age at injury and time since injury were most predictive of outcome for attentional–inhibitory control, while injury severity and frontal lobe injury predicted outcomes for social-behavioural regulation (Dennis, Guger, Roncadin, Barnes, & Schachar, 2001). The neuropsychological division of “cold” circuits as being involved in attentional control and “hot” circuits as being involved in behavioural regulation provides a credible explanation for these findings.

The addition of emotion to trials did not appear to have a significant main effect on any of the performance variables measured. In regards to accuracy of performance, only a significant main effect of trial type (go/stop) was found, with average accuracy on stop trials being slightly lower and variation in performance (*SD*) being somewhat higher than on go trials. However, the conclusions that can be drawn from this comparison are very limited, since very few errors were made on the overall task, regardless of condition. Thus, the expectation that inhibition on neutral trials would be different from the ability to inhibit on emotional trials was not seen in the current experiment. A significant main effect of RT was found only for presentation time, with RTs being smaller on long trials than on short trials. However, conclusions drawn from stop trial data were again very limited.

When average RTs on happy or angry trials were subtracted from participants’ RTs on neutral trials, no significant difference was found in these “difference scores” between happy and angry conditions. When differences in SDs of RTs were investigated across go trials, no significant main effects were found for emotion type or presentation time. These findings were unexpected, since studies with similar tasks, such as the Emotional Go/No go task, show significantly slower and more variable responses, and higher rates of commission errors with emotional face stimuli (from the same NimStim set) than with neutral stimuli (Schulz et al., 2007). However, the Schulz et al. (2007) study did have an important difference in experimental design: the neutral stimuli utilized in that study to compare performance with and without emotional valence were pictures of circles, rather than emotionally-neutral faces. Human faces and the amount of information they convey to the observer are quite complex when compared with a simple circle stimulus. Thus, it is impossible to know whether the differences in performance seen between the neutral and emotional Go/No Go tasks in that study were due to the emotion of the stimuli, the added complexity of processing a face over a circle, or a combination of these two factors. Importantly, the EMO-CPT offers a more direct experimental comparison of the effect of emotional and non-emotional faces on performance.

The interaction between emotion type and stimulus presentation time approached significance in the current study. This interaction suggests that the presentation time chosen does impact the effect of emotion on performance. Thus, it is possible that the trial lengths chosen in the current investigation were too long to bring about an effect of emotion. It could be that longer trial durations (stimulus presentations times) allowed participants adequate time to self-regulate and inhibit, regardless of the emotions evoked by stimuli. Perhaps shorter trial durations would have made accurate performance on the task more difficult, creating bigger effects of emotion on performance.

The internal validity of the EMO-CPT was good, with moderate correlations found amongst accuracy on all go trials, between accuracy and RT on go trials, between accuracy and RT *SD*s on go trials, and amongst RT *SD*s for go trials, and strong correlations found amongst RTs on go trials. Concurrent validity of the EMO-CPT was investigated by examining correlations between the Sustained/Speed factor and Accuracy/Inhibition factor and measures on the BRIEF, BART and CS. The Sustained/Speed factor correlated significantly with the BRIEF BRI, MI and GEC, and with more of the subscale measures from the MI (Initiate, Working

Memory, Plan/Organize) than from the BRI (Self-Monitor). This factor also correlated significantly with neutral, congruent, and incongruent RTs, and congruent and incongruent RT SDs on the CS.

Most of these correlations were predicted, and provide further evidence for describing the first factor as being related to "cold" cognition. However, the correlation between the "cold" Sustained/Speed factor and the "hot" BRI and its "Self-Monitor" subscale were not expected. Since correlations between this first factor and the BRI subscales were limited to the "Self-Monitor" scale, it seems likely that the ability to self-monitor is related to the functioning of "cold" circuits. More specifically, perhaps the ability to monitor one's own performance (as measured by the BRI "Self-Monitor" subscale) is related to the ability to sustain one's performance over time (as measured by the Sustained/Speed factor). Indeed, it seems likely that a mechanism that allows an individual to monitor their performance, check outcomes against desired results, and adjust behaviour accordingly, would be related to the ability to sustain performance when the task at hand requires it.

The Accuracy/Inhibition Factor was found to correlate significantly with the BRIEF BRI, two subscales of the BRI (Inhibit, and Self-Monitor), accuracy on neutral, congruent, and incongruent trials of the CS, and the difference score for incongruent-neutral accuracies on the CS. Correlations between this factor and the "hot" BRI and its subscales were expected. However, the correlations between this factor and the CS were not predicted, since the CS is thought to be a purely cognitive task, without an emotional component. Thus, it could be that the second factor may be more related to inhibition in general, rather than the specific ability to inhibit one's internal emotional reactions.

Correlations were investigated between EMO-CPT variables of interest and the BRIEF, BART, and CS. Accuracy on stop trials of the EMO-CPT was found to be significantly correlated with scores on the BRIEF BRI, *SD*s of the adjusted inflations score on the BART, and a difference score that compared accuracy on the CS on incongruent and congruent trial types. Since accuracy on stop trials (errors of commission) was expected to measure inhibition, the correlations between the "hot" BRI and BART and this variable were expected. This correlation with the "cold" CS accuracy difference score further supports the notion that accuracy on stop trials of the EMO-CPT measured the general ability to inhibit. This CS accuracy difference score was also found to be correlated with accuracy on neutral stop trials. Interestingly, this same CS difference score correlated significantly with the BRIEF MI index. This suggests that accuracy on neutral stop trials of the EMO-CPT taps the same "cold" cognition as the MI and CS. A difference score subtracting RTs on neutral go trials from those on happy go trials (H-N) was significantly correlated with the BRIEF BRI, suggesting that happy trials tap the same "hot" circuits as the BRI. Unexpectedly, a difference score subtracting RTs on angry go trials from neutral go trials (A-N) was significantly correlated with a difference score that compared RTs on the CS on incongruent and congruent trial types. This would suggest that angry trials tap the same "cold" cognition that is required to accurately inhibit the prepotent (but wrong) response on incongruent CS trials. This agrees with a bias found for happy faces on the emotional Go/No Go task which resulted in faster responses and more commission errors for happy than sad faces (Schulz et al., 2007). Perhaps faces with a positive valence (e.g. happy faces) signal an emotional "green light" for participants, encouraging them to respond faster, and causing them to make commission errors, while faces with a negative valence (e.g. sad or angry faces) signal an emotional "red light", encouraging caution in the responder, and thus lowering rates of error commission. It makes sense that greater behavioural regulation would then be required to continue responding with caution on happy trials than on angry trials.

Table 10.

Summary of main EMO-CPT findings according to variable, with interpretations and explanation of expected findings.

Variable/Factor	*Finding*	*Interpretation*	*Expected?*	*Why?*
Accuracy	• Only sig. main effect of trial type (go/stop): Accuracy on stop trials lower and variation in performance (*SD*) higher than on Go trials.	• Conclusions limited: very few errors made, so very few stop trials relative to go trials. • Emotion did not appear to effect accuracy.	No	• Expected inhibition on neutral trials to be different from inhibition required on emotional trials.
RT	• Only sig. main effect of RT for presentation time: RTs smaller on long trials than on short trials.	• Conclusions limited: very few errors made, so very few stop trials relative to go trials.	No	• Expected inhibition on neutral trials to be different from inhibition required on emotional trial, resulting in different RTs.
RT SD	• No sig. main effect of emotion or presentation time. • Emotion X presentation time interaction approached sig.	• Emotion did not appear to effect variability in RTs. • Presentation time might influence how emotion effects variance in RT.	No	• Expected inhibition on neutral trials to be different from inhibition required on emotional trial, resulting in different RT SDs.
Internal Validity	• Moderate correlations between: accuracies on all go trials, accuracy and RT on go trials, accuracy and RT *SD*s on go trials, RT *SD*s for go all trials. Strong correlations found amongst RTs on go trials.	• Internal validity was good.	Yes	• The task variables were all developed to tap similar constructs.
Factor Analysis	• 2 factor solution explaining 48.7% of variance.	• The two factors represent the functioning of “hot” and “cold” FSCs.	Yes	• Research shows EF involves “hot” and “cold circuits.

Factor 1	• Loaded negatively with RT and RT variability on Go trials, & positively with Accuracy on Go trials. • Labeled “Sustained/Speed” factor.	• Participants with shorter RTs and less variability in their RTs were more accurate. • Could be indicative of overall inattention.	No/Yes	• Speed/accuracy tradeoff expected. • Variability in RTs is with inattention.
Factor 2	• Loaded positively with accuracy on Stop trials & RT variables on Go Trials. • Labeled as “Accuracy/Inhibition” factor.	• Participants who were slower on go trials were also better at inhibiting on stop trials.	Yes	• Factor 2 predicted to be an index of cautiousness in responding.
Concurrent Validity				
Sustained/Speed Factor	Correlated sig. with: • BRIEF BRI, MI & GEC; & with more subscales form the MI than the BRI. • Neutral, congruent, & incongruent RTs, & congruent & incongruent RT SDs on the CS.	• Further evidence for describing the first factor as being related to “cold” cognition. • The ability to self-monitor is related to the functioning of “cold” circuits	Yes/No	• Correlation between this “cold” factor and the “hot” BRI and its’ subscale not expected.
Accuracy/Inhibition Factor	Correlated sig. with: • BRIEF BRI, two subscales of the BRI, accuracy on neutral, congruent, and incongruent trials of the CS, & the difference score for incongruent-neutral accuracies on the CS.	• This factor may be more related to inhibition in general, than the specific ability to inhibit emotional reactions.	Yes/No	• Correlations between this “hot” factor and the “cold” CS not expected since it’s a cognitive task, without an emotional component.
Accuracy Stop Trials Overall	• Sig. correlated with BRIEF BRI, *SD*s of the adjusted inflations score on the BART, & difference score comparing accuracy on the CS on incongruent and congruent trial types.	• Correlation with the “cold” CS accuracy difference score supports the notion that accuracy on stop trials of the EMO-CPT measured inhibition.	Yes	• Accuracy on stop trials was expected to measure inhibition. Correlations with the “hot” BRI and BART expected.
Accuracy Neutral Stop Trials	• Sig. correlated with difference score comparing accuracy on the CS for incongruent and congruent trial types.	• “Cold” cognition was required to be accurate on stop trials with neutral faces.	Yes	• Neutral trials were expected to tap “cold” circuits.

RT Happy-Neutral Go Trials	• Sig. correlated with the BRIEF BRI.	• Happy trials tap the same “hot” circuits as the BRI.	Yes	• Emotional trials were expected to tap “hot” circuits.
RT Angry-Neutral Go Trials	• Sig. correlated with difference score comparing RT on the CS for incongruent and congruent trial types.	• Angry trials tap the same “cold” inhibition required for incongruent CS trials.	No	• The “cold” CS was not expected to correlate with “hot” emotional trials.

Note: RT=Reaction time; *SD*=Standard deviation.

The Complex Relationship Between “Hot” and “Cold” EF

The results emphasize an important part of the EMO-CPT’s design: the task is primarily cognitive by nature. Participants were asked to categorize face stimuli based on hair-colour rather than emotion. Emotional valence of the face stimuli was extraneous to the task at hand. Thus, it seems likely that “cold” cognition would be required to successfully perform this cognitive task, regardless of the experimental condition, while “hot” behavioural regulation would be required only for emotional trials. The EMO-CPT task is therefore not designed to parse out the function of “hot” circuits in isolation from the cognition of “cold” circuits, but rather, a subtraction method must be used to draw conclusions about the functioning of “hot” circuits. As with any subtraction methodology, an unfortunate drawback of the EMO-CPT’s design is having to make assumptions about “hot” FSC functioning on emotional trials by removing all variability in “cold” FSC functioning on neutral trials. This ultimately makes the assumption that these specific cognitive processes can be added selectively in the two different conditions, and that differences in performance between the emotional and neutral conditions reflect the differing cognitive process. Further, this design assumes that a cognitive process such as behavioural regulation can be selectively added to the set of active cognitive processes involved in cold cognition without affecting them.

Thus, the hypothesis that performance on neutral EMO-CPT trials would correlate cleanly with measures of “cold” EF, and performance on emotional trials would be associated only with measures of “hot” EF was only partially supported. It appears that the factors stemming from the EMO-CPT, and their relationship with “hot” and “cold” cognition, may be more complicated than initially expected. Regardless, there did appear to be a general divide in the measures correlating with each factor, with pre-established measures of “cool” dorsal circuit function mostly correlating with the Sustained/Speed factor, and measures of “hot” ventromedial function generally correlating with the Accuracy/Inhibition factor. Thus, the EMO-CPT does appear to tap two different circuits. However, parsing apart the functioning of these circuits in isolation from each other may be considerably more complicated than previously appreciated. The complex relationship between “hot” and “cold” forms of EF, and the necessity of “cold” cognition for behavioural regulation should be appreciated in future research. These complex findings advocate for the importance of a cognitive processing perspective. Certainly, we cannot hope to reveal and understand interactions between “hot” and “cold” functioning within the brain without sophisticated neuropsychological understandings of the cognitive processing required to support these functions (Routledge. Fuchs, D., Hale, J. B., & Kearns, 2011). The development of tasks like the EMO-CPT to parse apart complex relationships in cognitive processing represents a positive step in neuropsychological research towards fully appreciating the intricate relationships between different domains of EF, and the FSCs that support these functions.

Limitations

Caution must be taken when generalizing the current results, since the participant population was quite homogenous (mostly highly-educated, female, Caucasian students, likely from a privileged social-economic background), and represented only a small proportion of the general population.

There were several limitations encountered in the design of the EMO-CPT, and the absence of any significant main effect of emotion may be partially attributed to these issues. The EMO-CPT may not have been a challenging enough task, as suggested by the ceiling effects in measures of accuracy, with average accuracy being close to 1. Stimulus presentation times used in the task were relatively long (1500 ms and 3000 ms). This may have led to the lack of omission errors found in performance. Perhaps trial durations (stimulus presentation times) were too long to allow for any effect of emotion on accuracy in performance. Further, the EMO-CPT did not include an inter-stimulus-interval (ISI), which created a problem when the same face, with the same emotion, was randomly presented twice in a row by the E-Prime software. Without an ISI, participants often were unable to tell the two trials a part, and thus did not respond on the second trial. Therefore, any trial which was preceded by a trial presenting the same face with the same emotion was excluded from analysis in the current study. Further, ISIs are important for brain imaging research, as they allow enough time between trials to parse apart changes in the brain that correlate with changes in each condition.

In terms of the overall study design, the BART did not prove to be as decisive an assessment of ventral circuit functioning as was desired. The BART, designed for children, may not have been suitable for the current study which included high-functioning young adults. Further, the design of the BART does not allow for a clear division between performance which is adaptive versus maladaptive, since the relationship between response pattern and earnings in nonlinear. It is important that a pre-established measure of “hot” EF parse apart adaptive responders from those who do not adjust their performance according to task outcomes. A task designed to measure “hot” EF which includes particular responses that are more advantageous than others would have better allowed the researchers to investigate learning curves, and participant adaptability.

We are limited in the conclusions that we can draw about the functioning of specific brain circuits in isolation. Since the FSCs are richly interconnected cortical and subcortical regions of the brain, functions cannot be entirely attributed and localized to the FSCs. In fact, a good general rule about brain functioning is that most functions are mediated by a many regions of the brain. For example, the fact that damage to many different regions of a particular brain circuit can produce executive dysfunction analogous with that seen when the frontal lobes are directly impaired provides evidence for this. Thus, we must cautiously avoid the reductionist temptation to revert to phrenological designations of particular brain circuits to specific functions. It is more accurate to describe the FSCs as major contributors to certain abilities (Zillmer, Spiers, Culbertson,2008). Finally, until functional imaging studies are completed with the EMO-CPT, conclusions cannot be confidently drawn about specific areas of the brain (or circuits) that are connected with performance on each factor.

Future Directions

Subsequent modifications to the task will include adding an inter-stimulus interval of either 1000 ms or 3000 ms, and a standardized stimulus presentation time of 500 ms. A varied ISI and decreased duration of the stimulus presentation should make the task more difficult and increase commission and omission errors. These parameters are closer to those used in most current CPT’s such as the Conners Continuous Performance Test (Conners, 1995). Further, removing the 50% emotional trials, and using only 100% emotional faces may intensify the effect of emotion on performance in the EMO-CPT. Follow up studies with the EMO-CPT should include a measure of “hot” EF which allows for a clearer division of advantageous versus disadvantageous decision making (e.g. the Iowa Gambling Task). Finally, the investigators aim to eventually utilize the EMO-CPT with clinical populations, and in an fMRI paradigm, to further elucidate whether this task can differentiate between different forms of circuit impairment, and reveal whether the brain regions assumed to be tapped by the different conditions of this task are indeed active.

Conclusions

Measures of EF often target only one aspect of executive processing, necessitating administration of multiple measures to evaluate frontal-subcortical circuit function.
A single task designed to tap multiple executive circuits could reduce test administration time and cost. By assessing multiple executive domains in one task, such a task may allow for streamlined examination of populations with executive dysfunction. The current study was the first step in establishing the EMO-CPT as a task that may be able to tap both “cool” dorsal circuits and “hot” ventral circuits. Two main factors did indeed derive from this task, however, the division of these two factors along “cold” and “hot” cognition is not entirely justified by the current findings. These ambiguous results may be due to a ceiling effect caused by the ease of the current task. Future studies will adjust the design of the EMO-CPT to investigate whether the effect of emotion on task performance will become clearer.

Once validated, the EMO-CPT has the potential to become a standardized tool used to evaluate different executive impairments found in different executive dysfunctions. This task may have relevance for differential diagnosis and monitoring treatment response in neuropsychiatric disorders. Further, the EMO-CPT presents conditions that reflect real-life situations more accurately than many conventional tasks of EF, and may therefore provide greater ecological validity. Future research with fMRI and other neuropsychological measures will establish the EMO-CPT as a measure that taps the functioning of frontal-subcortical circuits related to external (“cool” dorsolateral-dorsal cingulate) and internal (“hot” orbital-ventral cingulate) cognitive and behavioural regulation.

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Appendices

Appendix A
Participant Consent Form

University of Victoria
Office of The Vice-President, research
Human Research Ethics Committee

Participant Consent Form

Face Recognition and Attention

You are invited to participate in a research study that investigates the relationship between recognition of different facial expressions and paying attention to them. This study is being conducted by Drs. James B. Hale, Adam Krawitz, and Jim Tanaka, professors in the Department of Psychology at the University of Victoria. This study has been approved by the University of Victoria Human Research Ethics Board. You may verify ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria at 250-472-4545 or email at ethics@uvic.ca. The following informed consent is required by the University for any person involved in a University-sponsored research study.

The purpose of this research is to examine the relationship between types of facial expressions and how they affect attention and hand movement. We will ask you to do three computer tasks, and then complete a rating scale about how you think, pay attention, and keep track of what you are doing. The computerized task with faces takes about 15 minutes to complete. Then we ask you to do a second task that requires you to attend to simple words and press one of four keys on the computer keyboard. For the third task we ask you to do one more task that is like a game where you blow up balloons on the computer screen to get points. Finally, we will ask you to complete the rating scale that asks you to circle the response that best characterizes your attention, thinking, and keeping track of what you are doing. Finally, there is a brief form asking you about your demographic information such as your age, gender, year in school, etc. Altogether your participation may take as much as 45-60 minutes to complete the entire research study.

The risks involved with this study are minimal. You could have a brief change in thoughts or emotions in reaction to some of the faces presented on the computer screen, but this is unlikely.

If you are participating in this experiment to satisfy a course requirement, you will receive the appropriate course credit upon completion. It is important for you to know that it is unethical to provide undue compensation or inducements to research participants. If you feel that you are being coerced into participation by this compensation, you should decline to participate.

Your participation in this research must be completely voluntary. If you decide to participate you may withdraw at any time without providing an explanation and without any negative consequences. If you had started this project to fulfill a course requirement, your professor will not be informed of your agreement to participate and/or decision to withdraw.

Your confidentiality and the confidentiality of all the data will be protected by storing the consent form, as well as any other related materials, in a locked filing cabinet in the laboratory of Dr. James B. Hale. File cabinets and computers on which data are stored are located in locked laboratory rooms to which only authorized personnel have access. The results of this research may be presented at scholarly meetings and published in scientific journals, but all information regarding your identity will not be disclosed and will always remain confidential.

Your signature indicates that you have read and understood the information provided above; that you willingly agree to participate; that you may withdraw your consent at any time and discontinue without penalty; and that you are not waiving any legal claims, rights, or remedies.

If you have any questions, do not hesitate to ask the researcher. You may also contact Dr. Hale. Thank you.

A copy of this consent will be left with you and a copy will be taken by the researcher.

Name of Participant	*Signature*	*Date*

Appendix B

Experiment Script

Department of Psychology - University of Victoria

E-CPT Research Protocol
Research Assistant Script

Rapport Building

“Hi, my name is ____________________, and I am a Research Assistant working under Drs. Hale, Krawitz, and Tanaka, professors in the Department of Psychology. Thank you for coming in today for our research project.”

“What’s your name (PAUSE FOR NAME)? Nice to meet you. We are going to do some things today on the computer, and I’ll be asking you to fill out some questionnaires.” (PULL OUT A NEW FOLDER).

Informed Consent

“The first thing we need to do is what’s called Informed Consent (GET INFORMED CONSENT FROM FOLDER, GIVE PARTICIPANT INFORMED CONSENT FORM). Informed consent is like a contract between you and us, the researchers. It helps you decide whether you want to do our research project, and lets you know you can quit doing it at any time if you feel uncomfortable in any way without being penalized, and you’ll still receive credit for coming in today. Let’s read it together.”

READ INFORMED CONSENT FORM. READ IN SLOW DELIBERATE PACE, BUT RAISE AND LOWER VOICE TO INDICATE PUNCTUATION.

“Does that make sense to you? Do you have any questions (PAUSE FOR QUESTIONS)? If not, please print, sign, and date the form here (POINT TO SIGNATURE LINE and WAIT FOR SIGNATURE). That is your form for the research project so you have a copy. Here’s the same form for our records, please print and sign your name, and date it too (MAKE SURE ALL COMPLETED AND RETURN THIS FORM TO THE FOLDER).”

“OK, thanks for doing that. We are ready to begin. We start out by doing a task on the computer that requires you to look at some faces on the screen (POINT TO COMPUTER AND MAKE SURE PARTICIPANT IS SQUARELY FACING THE COMPUTER SCREEN). Are you ready to begin?”

INTRODUCE EMO-CPT THROUGH DIRECTIONS ON SCREEN. AFTER INTRODUCTIONS AND BEFORE TASK, SAY:

“OK, are you ready to begin? Do you have any questions? OK, please work hard at looking at the screen and pressing the space bar when you see the blond haired man. This task takes a little time, so please keep trying your best throughout the task, OK? Press the space bar when you are ready.”

OBSERVE PARTICIPANT PERIODICALLY DURING EMO-CPT TO ENSURE THEY ARE LOOKING AT THE SCREEN AND PRESSING SPACEBAR; DO NOT STARE AT HIM/HER, BUT LOOK UP PERIODICALLY TO LET THEM KNOW YOU ARE AWARE OF WHAT HE/SHE IS DOING.

AFTER COMPLETION OF EMO-CPT, SAY:

“OK, nice work on that. I appreciate your effort. It was a long task, but I’m glad you kept working throughout it. Ready for your next task (PAUSE)? OK, this one requires you to press number keys here (POINT TO NUMBER KEYS). Let’s read the directions together.

INTRODUCE COUNTING STROOP THROUGH DIRECTIONS ON SCREEN. AFTER INTRODUCTIONS AND BEFORE TASK, SAY:

“OK, are you ready to begin? Do you have any questions? This task also takes a little bit of time, so please keep working hard throughout the task, OK? Press the key when you are ready to begin.”

OBSERVE PARTICIPANT PERIODICALLY DURING COUNTING STROOP TO ENSURE THEY ARE LOOKING AT THE SCREEN AND PRESSING NUMBER KEYS; DO NOT STARE AT HIM/HER, BUT LOOK UP PERIODICALLY TO LET THEM KNOW YOU ARE AWARE OF WHAT HE/SHE IS DOING.

AFTER COMPLETION OF THE COUNTING STROOP, SAY:

“OK, two down, one more to go. This task is a little different in that it is like a game. The goal of the game is to blow up balloons here on the computer screen for points, but not let the balloons pop. Let’s read the directions together.”

INTRODUCE BART THROUGH DIRECTIONS ON SCREEN. AFTER INTRODUCTIONS AND BEFORE TASK, SAY:

“OK, are you ready to begin? Do you have any questions? This task also takes a little bit of time, so please keep working hard throughout the task, OK? Press the spacebar when you are ready to begin.”

OBSERVE PARTICIPANT PERIODICALLY DURING BART TO ENSURE THEY ARE LOOKING AT THE SCREEN AND PRESSING THE SPACEBAR; DO NOT STARE AT HIM/HER, BUT LOOK UP PERIODICALLY TO LET THEM KNOW YOU ARE AWARE OF WHAT HE/SHE IS DOING.

AFTER COMPLETION OF THE BART, SAY:

“OK, nice work, thanks for doing these tasks. We are now done with the computer tasks and almost done with the project. Are you doing OK? Need a break (PAUSE)? OK, let’s finish up. Next we have a questionnaire we want you to fill out, here’s a pencil (HAND PENCIL TO PARTICIPANT). Let’s read the directions together (READ DIRECTIONS FOR BRIEF). Please fill out all items, even if you think you need to explain your response. After, we can go over the items you have any questions about. OK, do you have any questions before we begin (PAUSE)? You may begin.”

OBSERVE PARTICIPANT PERIODICALLY DURING BRIEF TO ENSURE THEY ARE READING BRIEF ITEMS AND CIRCLING RESPONSES; DO NOT STARE AT HIM/HER, BUT LOOK UP PERIODICALLY TO LET HIM/HER KNOW YOU ARE AWARE OF WHAT HE/SHE IS DOING.

“OK, do you have any questions about the items (PAUSE, AND IF NO QUESTIONS RETURN BRIEF TO FOLDER). Great, a couple more questions and we are done. This is a brief questionnaire about your background (HAND OUT DEMOGRAPHIC QUESTIONAIRE). Please fill this out and we’re done.”

OBSERVE PARTIPANT FILL OUT THE DEMOGRAPHIC QUESTIONAIRE TO MAKE SURE ALL ITEMS ARE COMPLETED. WHEN DONE, SAY:

“Excellent, thanks (PUT DEMOGRAPHIC QUESTIONAIRE IN FOLDER)! OK, the last thing we need to do is the debriefing. A debriefing explains to you what the study is about. Please don’t tell any of your friends in your classes what the study is about, because that could change how they do the study if they volunteer, OK?

READ DEBRIEFING TO PARTICIPANT.

“OK, any questions? Thanks so much for doing this project. I hope you have learned a little bit about research here, and you have also completed the project for class credit. Andrea Schneider, Research Laboratory Director, will be letting your professor know that you received credit for doing the study. You can contact Dr. Hale if you have any questions, OK? Hey, thanks again for working hard on this study (STAND UP AND SHAKE PARTICIPANT’S HAND (IF YOU WANT), AND OPEN DOOR FOR PARTICIPANT). Have a good one!” (PUT FILE IN LOCKED FILE CABINET, AND NOTIFY ANDREA VIA EMAIL OR PHONE PARTICIPANT IS DONE – GIVE ONLY PARTICIPANT NUMBER IN EMAIL, NOT NAME).

END OF SCRIPT

Note that if a participant asks a question during the study that might reveal too much about the purpose of the experiment, just politely let them know that it’s a good question, and you can answer it at the end of the study.

Appendix C

Demographic Questionnaire

Participant Code# ________
Date:__________

BACKGROUND INFORMATION QUESTIONNAIRE

1. Age: ______
2. Gender: (Male/Female) _____________
3. Education: (Last Grade or Year Completed) ___________________________
4. Estimated average University grade (circle):

   A+ A A- B+ B B- C+ C C- D F
5. Handedness: (Right/Left) ____________
6. First Language: (Specify) ______________________
7. Have you been diagnosed with a disorder or disability (e.g., depression, learning disability, attention deficit hyperactivity disorder)? (Yes/No) ______

   If yes, please indicate disorder/disability:

   ____
8. Have you ever sustained a concussion or brain injury? (Yes/No) ______

   If yes, please explain:-

   ____
9. Do you suffer from any neurological disorders (e.g., Epilepsy)? (Yes/No) ______

   If yes, which disorder?

   ____
10. Are you currently taking any medications? (Yes/No) ______

    If yes, please specify:

    ____
11. Is there anything extraordinary about today, that you feel may influence the results of the study (e.g., lack of sleep, illness, hungry)

    (Yes/No) ______

    If yes, please specify:

    ____

Appendix D

Debriefing Form

Participant Debriefing Form

Thank you for your participation in this research project. Your time and efforts are greatly appreciated. This debriefing form will describe the research in greater detail so you can understand the purpose of the study.

This E-CPT study will help contribute to a growing literature on the relationship between different aspects of executive function and behavior. Executive functions are essentially the self-management or s “brain boss” skills needed to adapt successfully to one’s environment. Executive functions include things like planning, organization, strategizing, monitoring, evaluating, and changing your behavior. They are also related to attention and impulse control. Executive functions are most often thought to be a function of the frontal lobes. However, recent research has suggested there are “hot” parts related to emotion self-regulation, and “cool” parts that are related to task self-regulation. So while the “hot” executive functions are about internal self-control (keeping control of yourself), the “cool” executive functions are about external self-control (keeping control of the task you are doing).

This project was undertaken to examine the validity of the University of Victoria Emotional Continuous Performance Test (UVic EMO-CPT). The EMO-CPT is the first test you took with the faces. One of the other computer tests, the number test, is related to “cool” executive functions. The third test, balloon test has been related to “hot” executive functions. The rating scale you completed also has “hot” and “cool” sections, and gives us scores for each of these. Our hope is that the EMO-CPT will measure both “hot” (the emotional face trials) and “cool” (the neutral face trials) functions by seeing relationships among EMO-CPT variables and the other measures in the study. If our hypotheses are supported, we will eventually look to see if EMO-CPT performance affects patterns seen on brain scans using fMRI (functional magnetic brain imaging). If results are positive, the UVic EMO-CPT would be the first test that can be used to examine both “hot” and “cool” executive functions all in the same test.

Thank you again for your participation. Should you want to discuss the project further, please don’t hesitate to contact Research Laboratory Director Andrea Schneider or Dr. Hale.