Deriving an Executive Behaviour Screener from the Behavior Assessment System for Children – 2: Applications to Adolescent Hockey Players With and Without Concussions

By

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Supervisory Committee

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Abstract

Objective: Executive functions govern our ability to navigate complex and novel situations in day-to-day life. There is increased interest on environmental influences that may cause changes to executive functioning. The current thesis involves two studies examining the derivation and performance of an executive behaviour screener from the Behavioral Assessment System for Children (BASC-2-PRS; Reynolds & Kamphaus, 2004) on two different adolescent samples using a previously derived four-factor model of executive functioning (Garcia-Barrera et al., 2011, 2013). **Participants and Methods:** *Study 1.* BASC-2 PRS standardization data consisting of a demographically matched American sample of 2722 12-21 year olds was obtained. The screener was derived using 25 items assigned a priori to each executive factor. Confirmatory factor analysis (CFA), invariance testing, and multiple indicators multiple causes (MIMIC) models were used to evaluate the screener. *Study 2.* The screener was applied to a previously collected sample of 479 elite adolescent hockey players from Canada with or without a history of concussion, followed through a single season of play. CFA, invariance testing, and MIMIC models were used to evaluate the screener and the hockey sample was compared to the standardization sample. **Results:** *Study 1.* Acceptable-to-good reliability was obtained for all factors (α = .75-.89). The four-factor model was the best fit to the data (CFI = .990, TLI = .989, RMSEA = .037). Configural, metric, and scalar but not latent mean invariance was shown for sex. Age-related uniform differential item functioning (DIF) and SES-related uniform and non-uniform DIF were shown. Standardized norms for use in clinical settings were created. *Study 2.* Acceptable-to-good reliability was shown for 3 factors (α = .72-.85). Emotional Control showed poor reliability (α = .58).

The four-factor model was the best fit to the data (CFI = .991, TLI = .990, RMSEA = .026). Configural, metric, and scalar but not latent mean invariance was shown between the two samples. Uniform and non-uniform DIF were not observed for those with an increasing number of past concussions. **Conclusions:** Findings support the four-factor model measured through the screener in adolescence. Females and hockey players demonstrate fewer executive behaviour problems overall. Sex, age, and SES may influence the interpretation of factor scores. Continued exploration and development of the screener is suggested.

Keywords: executive function, adolescents, confirmatory factor analysis, differential item functioning, concussion

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Chapter 1. Concussions and Executive Functions in Adolescence

Introduction

The purpose of this chapter is to underscore the importance of an increased understanding of sports concussion and their potential effects on cognitive functioning (e.g., executive functions) in the context of adolescent development. With this need in mind, a latent four-factor screener for executive behaviours will be derived from the standardization sample of the Behavior Assessment System for Children – 2, a commonly administered omnibus behavioural assessment measure, in order to examine the effects of concussion on the development of executive functions in a sample of adolescent athletes. The overall goal of the study is to develop a reliable clinical measurement tool for clinicians to use when assessing for executive behaviour change after a concussion. To understand the context and process in which this tool was derived, the relationships between concussions, adolescent development, and executive functions and their measurement must first be examined.

Preventable injuries lead to nearly 3.5 million emergency department visits with a total economic cost of 26.8 billion dollars each year in Canada (Parachute Canada, 2015). For Canadian adolescents, 64% of hospital emergency room visits are related to participation in sports and physical activities (Government of Canada, 2016). Among those adolescents entering emergency departments with sports-related head injuries, the vast majority suffers from concussions with over 15,000 individuals visiting emergency departments in Alberta and Ontario in 2015 alone (CIHI, 2016). In the past 15 years there has been an increasing concern surrounding concussions in youth contact sports like hockey (Johnson, 2011; King & LeBlanc, 2006; Marchie & Cusimano, 2003), with medical organizations like the Canadian Academy of Sport and Exercise Medicine

(CASEM) advocating for a targeted, age-restricted ban on body checking in an effort to reduce the number of concussions in youth hockey (Kissick, 2007). In Canada, over 30 percent of individuals who played sports as children or adolescents reported suffering concussions or suspected concussions, with half of these individuals never being formally diagnosed (ARI, 2015) supporting the idea that epidemiological data for concussion rates are generally considered to be far lower than the actual incidence rate as many people do not seek medical attention when they receive concussions (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). These rates of concussion are particularly concerning as concussions can affect higher cognitive processes, like executive functions (Karr, Garcia-Barrera & Arenshekoff, 2014a) and this has widespread implications for public health policy and economic development where these cognitive processes are heavily implicated in positive and adaptive social outcomes (Scorza, Araya, Wuermli, & Betancourt, 2015). Due to the widespread prevalence of concussions it is important to understand what they are, how they manifest in individuals, and what risks are associated with receiving concussive injuries.

Concussion Symptomatology and Management

Concussions have traditionally been considered synonymous with mild traumatic brain injuries but a recent change in the conceptualization of this injury has led to a new conceptualization of this injury. Concussions are now seen as a neurocognitive or behavioural dysfunction resulting from a biomechanically induced alteration of brain physiology (McCrory et al., 2017). Biomechanical injuries to the brain due to concussion are generally diffuse in nature. Diffuse injuries are caused by the stretching and tearing of brain tissue (particularly axonal white matter) and do not necessarily require skull fractures, direct impacts, or crush injuries to the brain surface. Specifically, diffuse axonal injuries occur in the context of decelerative forces that cause the brain to twist apart and scrape against the interior of the skull cavity. The severity of axonal injury is directly proportional to the decelerative forces applied to the brain (Blennow, Hardy & Zetterberg, 2012). Based on the most recent global health guidelines (McCrory et al., 2017), concussion symptoms can be divided into the following categories: physiological symptoms (e.g., headache), behavioural changes (e.g., irritability), emotional disturbances (e.g., lability), cognitive impairments (e.g., impaired reaction times), and sleep problems (e.g., drowsiness). If one or more components are present in an examination, a concussion should be suspected. Individuals suffering from concussions are typically assessed by trained medical professionals using standardized concussion assessment tools, such as the Sport Concussion Assessment Tool Version 5 (SCAT5; ICCS, 2017). Additional clinical outcome information may be provided via neuroimaging techniques or neuropsychological assessment tools to aid in concussion management and treatment (Noble & Hesdorffer, 2013; Ritchie et al., 2014). A history of concussion is a documented risk factor for increased recovery times from subsequent concussions and an increased susceptibility to future brain injuries (Grady, 2010; McCrea, Broshek, & Barth, 2014). Individuals recovering from a recent concussion are also more vulnerable to receiving another brain injury, which markedly increases an individual’s susceptibility to developing cognitive deficits (Blennow et al., 2012; Noble & Hesdorffer, 2013).

Currently, many sport concussion management procedures advise rest until asymptomatic for concussions; there is insufficient evidence to support the use of rest to facilitate recovery beyond an initial 48-hour period and the most up-to-date concussion management guidelines prescribe six graduated stages of rehabilitation with each stage taking a minimum of 24 hours before an individual be allowed to progress to the following stage (McCrory et al., 2017). If any additional symptoms should occur while in this process, the patient should revert to the previous asymptomatic level and wait a further 24 hours. The six stages, from least to most strenuous are: No activity/rest, light aerobic exercise, sport specific exercise, non-contact training drills, full-contact practice, and return to play. For children and adolescents, a more conservative estimate of recovery is advised, and return-to-school should be prioritized over return-to-play. Return-to-school guidelines consist of four graduated stages to be followed in a similar manner as return-to-play guidelines: Daily activities at home, school activities, return to school part-time, return to school full-time.

Most concussion symptomatology resolves within a few weeks post-injury and the vast majority of individuals recover normal functioning in cognitive domains by 90 days (Karr, Arenshekoff & Garcia-Barrera, 2014b). There remain a percentage of individuals (10-15%), however, who report lingering symptoms for months or even years after the initial injury (Brooks et al., 2013; McCrory et al., 2017; Mrazik et al., 2016) and this failure to fully recover is typically characterized as a post-concussion syndrome. Although concussions can cause negative effects on physical and psychological functioning across the lifespan, it has been noted that adolescents in general seem to be at higher risk for experiencing the negative effects of concussions or mild traumatic brain injury than other age groups (Grady, 2010). In a systematic review of meta-analyses on the neuropsychological outcomes of concussion, Karr et al. (2014b) found clear support for adolescents being the age group at greatest risk of sustaining a concussion and most vulnerable to the negative effects of concussion. Additionally, adolescence has been thought of as a particularly sensitive period for the establishment of higher-order cognitive processes, such as executive functions (Scorza, Araya, Wuermli & Betancourt, 2015).

Executive Functions

Executive function is a term used to conceptualize a collection of complex cognitive processes traditionally associated with and carried out by the frontal lobes and related neural networks. A single definition that captures the essence of executive function has been difficult to establish (Goldstein, Naglieri, Princiotta & Otero, 2014; Jurado & Rosselli, 2007). Diverse characterizations of executive function have included concepts like planning, cognitive flexibility, attentional control, inhibition, and concept formation (Jurado & Rosselli, 2007). Importantly, executive processes are most engaged in novel contexts where situational cues and guidelines are unclear.

Importance of Executive Functions in Daily Life

Normal development of executive functioning is associated with a wide range of positive outcomes including but not limited to physical and mental health; educational and employment outcomes; and productive and healthy relationships (Diamond, 2013; Scorza et al., 2015). For example, better attentional control in childhood improves the odds that an individual will graduate from college (McClelland, Acock, Piccinin, Rhea, Stallings, 2013). Conversely, as executive functioning governs complex and nuanced behaviours, damage to executive processes have been associated with a wide range of negative outcomes (Diamond, 2013). Executive functioning impairments are associated with problems in managing daily activities and participation in employment, education, and recreational activities (Hunt, Turner, Polatajko, Bottari & Dawson, 2013). Increased emotional and behavioural problems are associated with executive functioning deficits in children and adolescents (Cassidy, 2016). After controlling for intelligence, poorer executive functioning predicts obesity status in early adolescence, and higher levels of impulsivity specifically predicts the onset of alcohol and tobacco use in these age ranges (Stautz, Pechey, Couturier, Deary & Marteau, 2016). Additionally these deficits have been documented in individuals with ADHD (Qian, Shuai, Chan, Qian & Wang, 2013) and traumatic brain injuries (Howell, Osternig, Van Donkelaar, Mayr & Chou, 2012; Hunt et al., 2013; Lax et al., 2015; Mangeot, Armstrong, Colvin, Yeates & Taylor, 2002) for whom general life outcomes tend to be poorer than in healthy populations.

Executive Functioning in Adolescence

Adolescence is a complex, multifaceted developmental period, typically set between the ages 12-18, that is not easily defined by a single process or event. It is a developmental period characterized by rapid physiological, psychological, and social changes. Typically, adolescence is considered to begin from the onset of puberty and ends upon the achievement or establishment of physiological benchmarks, psychological maturation, and societal milestones associated with adulthood (Gullotta & Adams, 2005). Executive functioning tends to improve throughout childhood and into late adolescence with differences between male and female developmental trajectories consistently indicating superior effortful control in females (Else-Quest, Hyde, Goldsmith, & Van Hulle, 2006). Many of the changes that arise during this period reflect the improved capacity for executive functioning (e.g., improved inhibitory control) in adolescents as a consequence of age (Lax et al., 2015; Leon-Carrion et al., 2004; Tamnes et al., 2010) with many older adolescents being able to perform at adult or near-adult levels on most executive functioning tasks. The developmental improvements in executive functioning are mirrored by the temporally variable changes within adolescent brain structures (Tamnes et al., 2010).

Adolescent Brain Development

Adolescent developmental complexity is reflected in coinciding physical changes in white matter tract connectivity and grey matter volume in the whole brain (Crone, 2009; Gogtay et al., 2004). Neural structures associated with higher-order cognition like the anterior cingulate and prefrontal cortices become increasingly well developed through adolescence (Crone, 2009; Otero & Barker, 2014). The relatively late cortical thinning in frontal-parietal networks like the left dorsolateral prefrontal cortex and dorsal parietal cortices (Breukelaar et al., 2017; Gogtay et al., 2004; Squeglia et al., 2013) are characteristic of this developmental period. Brain regions such as the prefrontal cortex are among the last to mature, with synaptic pruning continuing into late adolescence (Alvarez & Emory, 2006; Selemon, 2013); this long developmental trajectory makes them particularly vulnerable to environmental influences (Aran-Filippetti & Richaud de Minzi, 2012; Hackman & Farah, 2008). Additionally, adolescent emotional development is stereotypically casted as an erratic and volatile period; interestingly, there is a neurological basis for this phenomenon as subcortical affective systems and structures (e.g., amygdala) demonstrate enhanced responding to emotional stimuli during adolescence (Crone, 2009).

Neural Correlates of Adolescent Executive Functioning

Distinct types of executive functioning progress through childhood and adolescence along different developmental trajectories (Anderson et al., 2001; Alvarez & Emory, 2006; Chen, Yan, Yin, Pan & Chang, 2014; Crone, 2009; Diamond, 2013; Gogtay et al., 2004; Huizinga et al., 2006; Leon-Carrion, Garcia-Orza & Perez-Santamaria, 2004; Qian et al., 2013; Selemon, 2013; Tomporowski, Lambourne, & Okumura, 2011) and this is reflected by the developmental variability across different brain regions. Contrary to the common belief that executive functioning is purely localized to the frontal lobes, meta-analytic reviews on the neural correlates of executive functioning point to multiple brain areas and inter-related neural circuitry such as frontal-subcortical systems (Alvarez & Emory, 2006) and frontal-parietal networks (Raichlen et al., 2016; Tamnes et al., 2010). Cortical thinning in frontal-parietal networks (Breukelaar et al., 2017; Gogtay et al., 2004; Squeglia et al., 2013) is associated with improvements in executive functioning. Indeed, lower integrity of volume in white matter tracts in children and adolescents is associated with lower cognitive flexibility (Ursache & Noble, 2016a). In other words, whole brain integrity is vital and necessary for the execution of executive functions (Jurado & Rosselli, 2007). Given the long periods of time in which adolescent brains and executive functions develop and the concern surrounding adolescent vulnerability to concussions, a discussion on concussions and other environmental factors that can influence the developmental trajectories of executive functions is warranted.

Environmental Impacts on Executive Functions

Adolescent brain development and by extension, executive functioning, is particularly influenced by environmental factors. Executive functioning can be influenced positively by factors such as physical activity (Guiney & Machado, 2012), sports participation (Russo et al., 2010), sport expertise (Huijgen et al., 2015; Vestburg, Gustafson, Maurex, Ingvar & Petrovic, 2012), and socioeconomic status (Aran-Filippetti & Richaud de Minzi, 2012; Ursache & Noble, 2016b), and negatively by factors such as concussion (Karr et al., 2014a) and stress (Crone, 2009). This sensitivity to environmental influences stems from the synaptic pruning processes during this developmental period in regions of the brain (e.g., prefrontal cortex) implicated in executive control systems (Selemon, 2013; Squeglia et al., 2013).

Positive Influences on Executive Functioning

Physical Activity and Executive Functioning

Despite the increased risk for traumatic brain injury in physical activities, there are also indications that participation in sports and other physical exercise activities may play a key role in the preservation or improvement of executive processes (Chang et al., 2014; Chen et al., 2014; Hung, Tsai, Chen, Wang & Chang, 2013; Tomporowski et al., 2011). Reinforcing these notions, a recent meta-analysis assessing the association between physical exercise and executive functions found small-to-moderate positive effect sizes of acute physical exercise on inhibitory control (Verburgh, Konigs, Scherder & Oosterlaan, 2014). Another meta-analysis found small but significant effect sizes during, immediately after, and after a delay for acute physical exercise on overall cognitive performance (Chang, Labban, Gapin & Etnier, 2012).

Participation in physical activity has been extensively linked to improvements in cognitive and psychological functioning spanning the lifespan (Etnier et al., 1997; Voss, Kramer, Basak, Prakash & Roberts, 2010) through childhood (Chen et al., 2014; Hillman, Erickson & Kramer, 2008), adolescence (Chen, Tseng, Kuo & Chang, 2016; Huang et al., 2015; Staiano et al., 2012), adulthood (Chan, Wong, Liu, Yu & Han, 2011), and older adulthood (Bixby et al., 2007; Tseng et al., 2013). Associations between frontal-parietal networks and default mode networks, which are implicated in executive functioning and physical activity in adult runners lends further support for this idea of the positive influence of exercise (Raichlen et al., 2016).

The association of improved cognitive functions and physical health is proposed to be in part due to increased cerebral blood flow (Sibley & Etnier, 2003), learning (Best, 2010), and neurogenesis (Tomporowski et al., 2011). Furthermore, there is some indication that being physically unhealthy (e.g., having increased adiposity) is associated with worse executive function in adolescence (Huang et al., 2015; Staiano et al., 2012; Tomporowski et al., 2011), where higher adolescent Body Mass Index (BMI) is associated with structural deficits in the orbitofrontal cortex (Reinert, Po'e & Barkin, 2013). Even for high-level collegiate athletes (individuals who are expected to be physically fit), higher BMI is negatively correlated with visual motor speed and visual and verbal memory (Fedor & Gunstad, 2013).

Sports and Executive Functioning

Beyond the positive associations between physical activity and general cognitive function, there is support for the idea that specific types of sports (i.e. open vs. closed sports) may confer differential benefits to an individual's cognitive abilities (Best, 2010; Russo et al., 2010; Wang et al., 2013). Open sports are typically defined as sport activities that require players to interact with a dynamic and unpredictable environment that is externally paced, which means players must make rapid decisions based on events outside of their immediate control (e.g., basketball, hockey, soccer, etc.); conversely, closed sports are defined as sport activities that involve a highly predictable and stable environments where players are self-paced (e.g., sprinting, swimming, endurance races, etc.; Russo et al., 2010). Competitive aspects of these physical activities may further bolster gains in EFs through cognitive representations of self and others in order to win, which increases demands on the prefrontal cortex (Staiano et al., 2012).

There is evidence demonstrating an association between participation in open sports versus closed sports for improved executive functions like inhibitory control (Wang et al., 2013; Huang et al., 2015), processing speed and attentional control (Voss et al., 2010), and problem solving (Jacobson & Matthaeus, 2014). While closed sports may confer cognitive benefits through physical activity in general, there is a common notion that these sports may not necessarily require the executive functions vital for success in more dynamic and unpredictable sports. However, evidence is equivocal as some studies found greater scores of inhibition within closed sport athletes compared to open sport athletes (Jacobson & Matthaeus, 2014). Interestingly, even for populations of physically disabled athletes, executive function task performance is comparable to healthy non-athletic controls for disabled basketball players, but not disabled swimmers, thereby demonstrating the beneficial effects of cognitively demanding sports (Russo, et al., 2010).

Sport Expertise and Executive Functioning

The role of sports expertise interacts with an athlete’s physical fitness to influence executive functioning. In young adults, high-fitness fencers demonstrate more accurate inhibitory control on Go/No-Go tasks compared to average and highly fit non-fencer controls, whereas average-fitness fencers do not (Chan et al., 2011). Professional

Japanese baseball players demonstrate significantly faster inhibitory control than tennis players, lower-skill baseball players, and non-athlete controls on Go/No-Go tasks while having similar base reaction times (Kida, Oda & Matsumura, 2005). Elite European adolescent soccer players exhibit greater inhibitory control and cognitive flexibility than their sub-elite counterparts (Vestburg et al., 2012) with differences remaining after controlling for training time and academic level (Huijgen et al., 2015). The additional benefit of sport expertise on executive functioning is likely due to the cognitive demands inherent in these complex cognitive and motor tasks that causes activation in the prefrontal cortex (Best, 2010) and emerges in parallel through continued practice and environmental feedback (Tomporowski et al., 2011).

Negative Influences on Executive Functioning

Concussions and Executive Functioning

Executive functioning is particularly vulnerable to multiple concussions (Karr, et al., 2014b), as executive functioning requires whole brain integrity and concussive impacts can cause widespread and diffuse axonal tearing. It has been noted that adolescent athletes are a particular subgroup of adolescents that is at highest risk for concussion (Karr et al., 2014b) due to consistent exposure to concussive and sub-concussive impacts (McCrea et al., 2015). Short-term cognitive disabilities have been reported in concussed youth but the long-term cognitive deficits are not clearly elucidated (Noble & Hesdorffer, 2013).

When adolescents are injured due to concussion they report slower recovery rates than their college-aged counterparts (Semrud-Clikeman & Klipfel, 2016). After receiving a concussion, young athletes demonstrate lower levels of cognitive flexibility and inhibition compared to athletes who did not suffer a concussion, with performance on cognitive tasks returning to baseline after an average of 20 days (Lax et al., 2015). Adolescent athletes with concussions exhibit significantly higher reaction times for the Attentional Network Test conflict effect component and greater switch costs on the Task Switching Test compared to controls (Howell et al., 2012). Concussed adult athletes show significantly increased activation in DLPFC, left parietal, and cerebellar areas during spatial memory navigation tasks, compared to non-concussed athletes, despite similar performance levels, indicating potentially compromised cognitive processing in brain regions associated with executive functioning (Slobounov et al., 2010).

Evidence for long-term cognitive deficits or problems due to concussion is equivocal as healthy elite adolescent hockey players with a history of concussions do not always show neurocognitive deficits on computerized test batteries compared to healthy players without a history of concussion, but do report higher levels of subjective symptomatology (Brooks et al., 2013).

Despite inconsistencies on test performance, neurophysiological differences can persist up to 6 months post-concussion. Furthermore, adolescents are the most sensitive to the effects of concussion compared to children and adults (Baillargeon, Lassonde, Leclerc & Ellemberg, 2012), suggesting a slower recovery process than outlined in current concussion clinical guidelines. Preliminary evidence in adolescent athletes indicate significant changes in white matter integrity for those receiving concussive impacts, and to a lesser extent, sub-concussive impacts compared to non-concussed controls (Bazarian, Zhu, Blyth, Borrino & Zhong, 2012).

Adult ice hockey players with a prior history of concussions demonstrate long-term deficits in performance with divided attention tasks compared to healthy athlete controls (Tapper, Gonzalez, Roy & Niechwiej-Szwedo, 2017). Indeed, there appears to be a disruption in different resting state networks after the resolution of clinical symptoms that is seen in functional magnetic resonance imaging and white matter tract abnormalities in diffusion tensor imaging due to concussion that is consistent with lasting injury in football, soccer, and hockey players (Noble & Hesdorffer, 2013). Additionally, white matter tract abnormalities in concussed collegiate athletes have been shown to persist beyond one month post-concussion (Meier et al., 2016).

Low Socioeconomic Status and Executive Functioning

Socioeconomic status (SES) is a multidimensional construct that reflects access to economic resources, power, prestige, and social class with the most common indicators used to denote SES being income, education, or occupation (Ursache & Noble, 2016b). Importantly, as children and adolescents have not yet established their own independent socioeconomic standing, the status of their parents or guardians is the next best measure (Hackman & Farah, 2008). The association between socioeconomic status and executive functioning is noteworthy in the context of sports participation and physical activity as many sports also involve a fairly high degree of economic resources and time, which is something not all families are necessarily capable of providing. In Canada, sports participation for children is highest in the top quintile of income at 68%, and lowest in the bottom quintile, at 44% (Clark, 2008). Therefore, any research concerned with associations between concussions, sports, and executive functioning should be mindful of the influence of other factors (particularly socioeconomic status) on these variables.

Socioeconomic status influences cognition and brain development, with differences between low and high SES groups in executive functioning and academic achievement being reported across the lifespan (Hackman, Farah & Meaney, 2010). Furthermore, this disparity in executive functioning does not decrease over time (Hackman, Gallop, Evan & Farah, 2015). Low SES is associated with poorer overall executive functioning in children (Aran-Filippetti & Richaud de Minzi, 2012; Ursache & Noble, 2016a) and decreased white matter tract integrity in the right parahippocampal cingulum and right superior corticostriate tract which are both implicated in executive functioning processes (Ursache & Noble, 2016a). Having higher SES may even be protective for individuals who have structural deficits in neural systems associated with executive function (Ursache & Noble, 2016a).

Stress and Executive Functioning

The associations between reduced executive functioning ability, changes in neural development, and low socioeconomic status is mediated by the environmental factors typically associated with low socioeconomic environments including but not limited to: poor parental practices, exposure to environmental toxins, poor nutrition, lack of environmental stimulation, and prenatal factors (Hackman et al., 2010). These environmental factors are stressful and the prefrontal cortex is particularly sensitive to stress. This may help explain why it becomes increasingly difficult to organize and inhibit behaviour in the context of increasing stress (Ursache & Noble, 2016b) contributing to weaker executive functioning. For adolescents, this association may be especially strong as their neurodevelopmental immaturity combined with intensified emotional experiences (which are inherently stressful) and other stressful experiences may lead some adolescents to demonstrate weaker executive abilities in the face of risky situations, emotional arousal or social influence (Crone, 2009), when they are typically able to perform at adult levels for most executive tasks. The interaction of positive and negative environmental influences on adolescent development, and executive functions paints a complex picture of what executive functions look like and provides a backdrop in which two contrasting but complementary methods for measuring executive functioning developed.

Measuring Executive Functioning

Executive functioning is traditionally assessed through two types of measurement, behavioural ratings and performance measures. Examples of behavioural rating scales include the Behavior Rating Inventory of Executive Functioning (BRIEF; Gioia, Isquith, Guy & Kenworthy, 2000) and the Behavioral Assessment System for Children – 2 and 3 (BASC-2 and BASC-3; Reynolds & Kamphaus, 2004; 2015) rely on self and other reports to inform clinicians of a person's current state of executive functioning. Broad omnibus measures like the BASC capture the essence of ecologically valid executive behaviours and assess executive functions in the context of typical behaviour in an unstructured environment (Toplak, West & Stanovich, 2013). Neuropsychological measures like the Wisconsin Card Sort Task (WCST; Berg, 1948), Delis-Kaplan Executive Functioning System (D-KEFS; Delis, Kaplan & Kramer, 2001), and Stroop Tasks (Stroop, 1935) rely on task performance and reaction times to gauge if there are specific neuropsychological deficits on executive processes. Performance on these measures reflects executive functions in the context of optimal performance in highly structured environments and assess for cognitive efficiency (Toplak et al., 2013). These kinds of measures have strong and consistent associations with frontal lobe function but should only be considered sensitive and not necessarily specific to frontal lobe damage (Alvarez & Emory, 2006). Interestingly, neuropsychological tests are not always consistent in indicating executive impairment with patients showing clear executive functioning problems and may sometimes indicate executive impairments in patients who demonstrate no problems with executive functioning in their daily lives (Pennington & Ozonoff, 1996). This inconsistency points to the complexity of executive functioning and the multitude of cognitive processes that underlie overt behaviours and also underlines the complementary nature of both kinds of measurement. Indeed, performance-based and ratings-based measures may be assessing different facets of executive functioning as there are only modest associations between the two modes of assessment (Toplak et al., 2013). The complexity of executive functioning and the difficulty of measuring these processes have led to a variety of approaches in studying executive functioning, which become even more complex in the context of the rapid developmental changes within adolescence.

Studying Executive Functioning

One of the most influential measurement-driven approaches to the study of executive function (Miyake et al., 2000) posits that executive functioning is composed of three fundamental processes: inhibition, shifting attentional control, and updating working memory. Inhibition relates to the ability to deliberately inhibit automatic or prepotent responses when necessary. Shifting attentional control refers to the ability to move back and forth between multiple tasks, operations, and mental sets. Updating working memory involves the ability to hold information in mind and manipulate the information when it no longer is perceptually present. Reflecting the diversity and unity of these executive processes, the three facets have been demonstrated to be moderately correlated but functionally distinct (Diamond, 2013).

A more recent, behavioural and measurement-driven conceptualization of executive function by Garcia-Barrera, Kamphaus, & Bandalos (2011) proposes a collection of four different latent factors: behavioural control, emotional control, attentional control, and problem solving. *Behavioural control* describes the ability to inhibit pre-potent responses and self-regulate behaviour. *Emotional control* describes the ability to self-regulate emotions in response to external and internal cues. *Attentional control* refers the ability to focus, sustain, and shift attention according to task demands. *Problem solving* refers to the ability to plan, make decisions, and structure information in the pursuit of a specified goal state. Using the Teacher Ratings Scale for Children (TRS-C) standardization data from the Behavioural Assessment System for Children (BASC; Reynolds & Kamphaus, 1992), a 25-item scale tapping into the four previously mentioned executive factors and with strong psychometric properties, was derived via Confirmatory Factor Analysis.

The four-factor model of executive behaviour has been replicated and validated with different BASC rating scales in populations of Colombian children with or without ADHD (Garcia-Barrera, Karr, Duran, Direnfeld & Pineda, 2015), kindergarteners from the USA (Sadeh, Burns, & Sulivan, 2012), Canadian university students (Duggan, Garcia-Barrera & Mueller, 2016), and has demonstrated its developmental stability in a longitudinal study on a sample of at-risk children (Garcia-Barrera, Karr & Kamphaus, 2013).

Comparing Approaches

While the four-factor model of executive function shares some conceptual similarities with the three-factor model, (e.g., inhibition being analogous to behavioural and emotional control) there remain a couple of key differences that separate the two approaches. First, the inclusion of problem solving in the four-factor model reflects a metacognitive aspect of executive functioning, which is required when preparing to execute a series of behaviours in response to novel situations (Garcia-Barrera et al., 2011). Metacognition in relation to executive functioning is not easily captured by task-based measures, which explains its exclusion from the three-factor model. Second, the three-factor model stems from performance-based computerized measures that are highly specific to a particular task but are more amenable to being operationalized as discrete executive functions, while the four-factor model is based on behavioural rating scales that are ecologically valid but do not directly examine the fundamental cognitive processes that make up executive function. This leads the three-factor and four-factor models to describe executive functions from two distinct but related levels, core cognitive processes and overt behaviours, respectively. It is important to note that this is an explanation of the two most relevant approaches to studying executive functions for the purposes of this discussion and is not an exhaustive review of every model or approach.

The Current Study

The objectives of this study are two-fold. First we are to ascertain whether an executive behaviour screener for adolescents could be derived from the BASC-2 Parent Rating Scale – Adolescent, replicating the approach previously applied to deriving screeners from different versions of the BASC for different age ranges and different referent populations. Second, we wish to apply this model to a sample of adolescent hockey players with and without concussions, to determine what effects concussion may have on executive functioning in this age range and if playing a sport has a buffering effect against damage to executive functioning due to concussions. In Canada, almost 500,000 youth play ice hockey (IIHF, 2016) with concussions being the most common injury type for these individuals (Echlin et al., 2010; Goodman, Gaetz & Miechenbaum, 2001) making this an ideal group of interest in the study of executive functioning and concussion in young athletes.

Previous studies have successfully derived an executive functions screener with other versions of the BASC in various populations (Garcia-Barrera et al., 2011, 2013, 2015; Sadeh et al., 2012; Duggan et al., 2016) and we expect that we would also be able to derive the same target instrument in this study. Based on the previous work done on the BASC executive function screener, we anticipate that a four-factor model will provide the best fit to the standardization data.

There have been no published studies to date deriving this executive behaviours screener in adolescent athletes or in the context of concussive injuries. Research has not yet established whether it is possible to use an executive behaviour screener to discriminate between concussed and non-concussed athletes. With this in mind, it is expected that the four-factor model will provide the best fit to the athlete data and it is expected that athletes will demonstrate fewer executive behaviour problems than the standardization sample. Furthermore, it is expected that athletes who have been concussed will show more executive behaviour problems than they demonstrated at baseline and that those with a history of concussions will have more executive behaviour problems than those who do not have a history of concussion. Finally, in order to aid future implementation of this screener, norms will be calculated from the standardization data.

Chapter 2. Methods

Study 1: Screener Derivation Methods

Participants

The first dataset consisted of the BASC-2-PRS-A standardization data provided by Pearson Assessment. This is a demographically representative sample of children and adolescents aged 12-21 in the United States. A total of 2,987 adolescents were sampled from the general population (for the full collection procedure, see Reynolds & Kamphaus, 2004) and self, teacher, and parent ratings were collected for each individual; ultimately 2,722 adolescents were retained for final analysis.

Measures

The BASC-2-PRS-A consists of 150 items, all of which are rated on a 4-point Likert-type scale (i.e., *Never, Sometimes, Often,* and *Almost always*) and is designed to capture many of the behavioural, emotional, and self-conceptual development issues specific to adolescence (e.g., “*Pays attention”* or “*Hits other adolescents”*) from the perspective of a parent or guardian, and that are relevant to normal executive functioning (Reynolds & Kamphaus, 2004). The BASC-2-PRS-A yields 4 composite scales and 14 individual content scales. Composite scales include Externalizing Problems, Internalizing Problems, Behavioral Symptoms Index, and Adaptive Skills. Content scales include Activities of Daily Living, Adaptability, Aggression, Anxiety, Attention Problems, Atypicality, Conduct Problems, Depression, Functional Communication, Hyperactivity, Leadership, Social Skills, Somatization, and Withdrawal. For the PRS-A, composite score reliabilities range from .90 to .95 and for individual scale scores from .72 to .88 in the general normative sample. Test-retest reliability ranges from .83 to .90 for composite scores and from .75 to .80 for individual scale scores. Inter-rater reliability ranges from .65 to .86 for composite scores and from .67 to .86 for individual scale scores. Several validity indices are included in the BASC-2 to give examiners an indication if a respondent has answered the rating forms in an overly negative or atypical manner. The F-index indicates overly negative responding; the consistency index is a measure of random responding based on different responses to similar items; and the response pattern index is a tally of inattentiveness to item content. Elevations on any of these indices may indicate that a respondent was not properly attending, understanding, or responding to the rating forms and that results should be treated with caution.

Screener Derivation Process

The entire item list of 150 items from the BASC-2-PRS-A was carefully examined and items that were potentially related to executive functioning were identified. This executive functioning designation is based on previous studies on the BASC-2 that established the behavioural screening measures that formed the following four constructs making up executive functioning: Problem Solving, Behavioural Control, Attentional Control, and Emotional Control (Garcia-Barrera et al., 2011; Duggan et al., 2016). The selection process for the pool of executive behaviour screener items followed several guiding principles and processes. First, all factor scales should consist of items that capture both the underlying latent construct as well as the complexity that each construct represents. Second, a relatively balanced set of items should compose each factor and when possible, items should be selected from a diverse range of original BASC-2 scale membership to avoid replicating an already pre-existing scale in the BASC. Third, a panel of 12 “experts” consisting of PhDs, graduate and honour students who were well versed in executive function reviewed the potential items for the scale and agreed upon their use with every item reaching 70% agreement. Through this process, a 25-item scale of executive behaviours was produced with a theorized 4-factor structure consisting of Problem Solving (6 items), Attentional Control (6 items), Behavioural Control (8 items), and Emotional Control (5 items). Likert values for all items on the PRS-A executive behaviour screener were recoded so that increasing values reflected increasing executive behaviour concerns. Upon confirmation of the CFA factor structure, scale scores for each executive behaviour factor were calculated via simple summation.

Reliability Analysis

Based on the original BASC executive behaviour screener derivation and supporting studies, critical values were set at |2.0| for skewness and |7.0| for kurtosis (Garcia-Barrera et al., 2011, 2013; Duggan et al., 2016). Indices of validity derived within the original BASC-2 scoring (i.e. F, Consistency, and Response Pattern indices) were examined to screen out any problematic patterns of responding (Reynolds & Kamphaus, 2004). Cronbach's α was used to estimate internal consistency reliability for each grouping of items. Accounting for the complexity of this four factor model of executive function and the small number of indicators being used to estimate each factor, internal consistency reliability values greater than 0.6 were determined to be acceptable and values greater than 0.7 as good (Hair, Black, Babin & Anderson, 2010; Kline, 2013). Frequencies and reliability coefficients were calculated using R (R Core Team, 2016).

Factor Analysis

Confirmatory factor analysis was used to assess the statistical properties of the four-factor model and its related indicators. The four-factor model will also be compared to the one-, two-, and three-factor models. A chi-square test, indicating goodness of model fit will conducted for each model, with values closer to zero demonstrating better model fit. To address concerns around chi-square tests being overly affected by large sample sizes (Marsh, Balla & McDonald, 1988), additional fit indices will used to more accurately assess model fit (Hu & Bentler, 1999). The comparative fit index (CFI) and root mean square error of approximation (RMSEA) will used. For CFI, scores closer to 1.0 indicate better fit. Scores above 0.90 indicate acceptable fit (Browne & Cudeck, 1993) and scores above 0.95 indicate good fit (Hu & Bentler, 1999). Conversely, scores closer to 0 indicate better fit for RMSEA with scores less than .08 indicating acceptable fit (Browne & Cudeck, 1993) and scores less than .06 indicating good fit (Hu & Bentler, 1999).

Invariance Testing

To reinforce the strength of the study's conclusions, invariance testing was conducted with gender (males vs. females). Three types of invariance testing (i.e. configural, metric, scalar invariance testing) will be conducted in a step-wise manner with each step incrementally providing evidence of factor invariance (Rusticus & Hubley, 2006). Latent mean equivalence was also conducted between genders (Vandenberg & Lance, 2000). Configural invariance testing assesses if the configuration of factor patterns is the same between groups (e.g., Do males and females have the same 4-factor structure for executive behaviours?). Evidence for configural invariance does not allow for between-group comparisons, as this is the minimum condition and weakest form of factor invariance (Horn & McArdle, 1992). If evidence for configural invariance is not found, this might indicate that the groups conceptualize constructs differently or attach different meanings to them (e.g., Behavioural control might mean something different for parents of males compared to females; Cheung & Rensvold, 2002). Metric (weak) invariance testing indicates if the factor loadings are equal across groups meaning individuals are responding to the items in the same way (e.g., Does the item "*Pays attention*" mean the same thing to parents of 12-14 year olds and 15-18 year olds?). Evidence for metric invariance allows for the comparison of correlations and regression coefficients for factors across groups but does not allow for comparisons of mean differences between groups (Steenkamp & Baumgartner, 1998). If evidence for metric invariance is not found, this might indicate that the latent variable was conceptualized differently between groups (Cheung & Rensvold, 2000). Scalar invariance testing indicates if individuals who have a particular value on a latent variable would have an identical value on the observed variable, independent of group membership (e.g., If males and females act equally impulsively, would parents rate them identically on the item "*Acts without thinking*"?). Evidence for scalar invariance allows for mean comparisons of factors between groups (Steenkamp & Baumgartner, 1998). If evidence for scalar invariance is not found, this might indicate a bias in how groups respond to the items (e.g., Parents of females require far less impulsive behaviour from their child to rate them highly on the item "*Acts without thinking*" than parents of males), thus mean comparisons between groups should not be made. Latent mean equivalence or invariance indicates that the latent, unobserved values of a factor are the same between two groups. This form of invariance is distinct from the other three types tested for in this study as it does not directly relate to the executive screener properties but relates to the properties of the sample itself. If latent mean invariance were to be established, it would indicate that the latent means of the two groups are identical, indicating no mean differences between groups.

Multiple inputs multiple causes (MIMIC) models

To test for invariance on continuous variables (e.g., age) we performed tests of differential item functioning (DIF) on each individual item through multiple inputs multiple causes (MIMIC) models (Fleishmann, Spector & Altman, 2002; Woods, 2009; Woods & Grimm, 2011) using age and SES as covariates and computed interaction terms for each executive behaviour factor. There are two kinds of DIF: uniform and non-uniform. Uniform DIF occurs when the likelihood of achieving a certain value on an item changes based on a group membership (e.g., people with low SES are more likely to score higher on item 80 than people with high SES). Non-uniform DIF occurs when the likelihood of achieving a certain value on an item varies based on an individual's proficiency (e.g. people with low SES will score higher on item 80 than people with high SES if they are also weaker in behavioural control but not when they are stronger). Items can demonstrate both uniform and non-uniform DIF simultaneously. This method of analysis is analogous to invariance testing but deals with continuous covariates as opposed to dichotomous grouping variables as in invariance testing. Uniform DIF is equivalent to scalar invariance and non-uniform DIF is the same as metric invariance. Factor analyses, invariance testing, and MIMIC model DIF testing will be conducted using R (R Core Team, 2016).

T-Scores and Z-Scores

T-scores were calculated from the standardization sample. In order to retain the fullest amount of information when producing the T-scores, any missing values in the standardization sample (~4% of total) were imputed via multiple imputation methods. Following imputation guidelines balancing accuracy, efficiency of calculation, and convergence (Bodner, 2008; Rubin, 1987; White, Royston & Wood, 2011), a total of 5 datasets were imputed with 20 iterations. Factor scores were computed for each dataset separately and were subsequently averaged and T-scores and Z-scores were generated from the mean imputed scores.

Study 2: Screener Application Methods

Participants

The second dataset was previously collected in a two mid-sized Canadian metropolitan regions. The original data was collected as a large cohort study of 44 hockey teams specifically designed to evaluate outcomes following concussive injuries (Brooks et al., 2013). This study constituted an authorized secondary use of data. For the sample used in the original study, participants registered with the local amateur hockey organizations were tracked for an entire season of play. Baseline measures were taken at the start of the season and player information was gathered throughout the season as part of the cohort study. Inclusion criteria for baseline testing were as follows: written informed assent/consent to participate (from the player and from one parent or guardian, respectively); either a male or female player; participation in Bantam (13-14 years) or Midget (15-17 years) leagues; the player must be playing in the most elite 20% of divisions of play (AA, AAA); players must have the agreement of their head coach to participate; and the team therapist must agree to participate in the study by collecting information about player participation and injury throughout the season. Exclusion of certain players from baseline testing occurred if they sustained an injury or had chronic illnesses that prevented full participation in hockey at the beginning of the season (i.e., all players were medically cleared for return to play). A total of 484 participants were tracked over the course of the season. A further subset of recently concussed participants and their parents completed one week (n = 83) and three month (n = 53) follow-up ratings post-concussion.

The main exclusion criteria for this study consisted of elements that would negatively impact the validity of the factor analysis, such as high scores on the F, Consistency, and Pattern of Responding indices of validity on the Behaviour Assessment System for Children-2 (Reynolds & Kamphaus, 2004) that would indicate some level of overly negative, inconsistent, or atypical response patterns. Furthermore, a diagnosis of learning disability or an indication that English is not the player's first language was also grounds for exclusion (Brooks et al., 2013).

Measures

The parents of all players completed Parent Rating Scale – Adolescent form of the BASC-2 (BASC-2-PRS-A; Reynolds & Kamphaus, 2004) at baseline and at subsequent follow-up sessions. Even though the BASC-2 normative sample was entirely drawn from the US population, the original BASC had Canadians in the normative sample with no distinctions being made between the two countries (Reynolds & Kamphaus, 1992). There also is evidence that indicates similarities between Canada and the United States in regard to rating scale response styles (Chen, Lee & Stevenson, 1995) and in the field of personality research (Allik & McCrae, 2004), which predominantly uses rating scales. Furthermore, the BASC rating system is one of the most widely used rating systems in North America (Rabin, Paolillo & Barr, 2016) and is used regularly in Canadian clinical practice. Reporting of previous concussions was assessed via pre-season questionnaires (PSQ). The PSQ is a previously validated measure used in injury surveillance studies in youth ice hockey (Emery & Meeuwisse, 2006). It is designed to be a pre-screening tool for medical, psychiatric, or behavioural concerns. The PSQ also collects demographic information including but not limited to: age, sex, medical history, and current sport participation status.

Refitting the CFA model

To ensure that the statistical model generated in Study 1 is applicable to this sample, it had to be refitted using the same steps as in Study 1. Finally, configural, metric, and scalar invariance were tested between those with and without a history of concussion in the sample of hockey players via MIMIC models. In addition, latent mean equivalence was tested between the two samples (Vandenberg & Lance, 2000).

Longitudinal sub-sample

A total of 36 individuals (7.5%) within the hockey sample had data collected for multiple time points (baseline, 1-week post-concussion, and 3-months post-concussion). Due to concerns around small sample size and low power, no statistical analyses were conducted with the subset of individuals who had multiple instances of parent ratings on the BASC-2. Figures were generated to map general changes in executive behaviour factor scores in relation to the norms generated in the first study.

Chapter 3. Results

Results

Data and item-level screening

The initial standardization dataset consisted of 2,987 individuals rated by their parents during the BASC-2 standardization process. Data was first screened for age and a total of 256 individuals in the dataset were less than 12 years old; these individuals were removed before the final analysis, leaving 2,722 individuals for the final count. The hockey player dataset consisted of 481 individuals rated by their parents over the course of single season of play. Validity indices on the BASC-2 were examined and 2 individuals were removed from the analysis for violating the Consistency Index and the Pattern of Responding Index, respectively. Though there were 53 individuals who had 3-month follow-up ratings completed, not every person had their 1-week post concussion follow-up information. A small subset of individuals had 1-week post-concussion, and 3-month post-concussion follow-ups ($n = 38$) ratings completed and these individuals were also examined separately after all other analyses were completed.

Internal consistency and reliability

Cronbach's α for the standardization sample from Study 1 ranged from .75 to .89 indicating acceptable-to-good internal consistency. There were no items in the entire 25-item scale in which their removal would improve reliability on any of the factor scores. When examining the hockey sample from Study 2, Cronbach's α for Problem Solving, Attentional Control and Behavioural Control were acceptable but slightly lower than the standardization sample ($\alpha = .72 - .85$). Reliability for Emotional Control was also lower than the standardization sample but was not within acceptable ranges ($\alpha = .58$). All

Cronbach's α can be found on Table 5. Similarly to Study 1, there were no items in the scale if removed, would have improved the reliability.

Descriptives

Study 1. For the standardization sample, 2,722 individuals with an average age of approximately 14.79 years (SD = 2.00) were retained for the final analysis. Demographic information, including sex and age distributions can be found in Table 1. Item-level descriptives including means and standard deviations can be found in Table 2. Mean item scores ranged from 1.07 to 2.43 (SD = .53-.96). Skewness and kurtosis were within the previously set normal ranges.

Study 2. For the hockey players, 479 individuals with an average age of 15.01 (SD = 1.20) were retained for the analysis. Demographic information can also be found in Table 1. Items 70 and 75 had skewness values over |2.0| due to low endorsement rates on those items. On average, hockey players had lower scores than individuals in the standardization sample.

Correlations

Study 1. For the standardization sample, inter-item correlations can be found in Table 3.1 and ranged from .19 to .70. Inter-factor correlations ranged from .58 to .76. All correlations were statistically significant ($p < .000$). The universal significance of all the inter-item correlations is unsurprising given the size of the standardization sample. Generally speaking, correlations between items theorized to belong to the same factor (e.g., Problem Solving) were stronger than between items belonging to different factors (e.g., Attentional Control or Emotional Control).

Study 2. For the hockey player sample, inter-item correlations can be found in Table 3.2 and ranged from -.02 to .62. Inter-factor correlations ranged from .44 to .70. Significance ranged from non-significant (p > .05) to highly significant (p < .0001) with the majority of correlations demonstrating some level of statistical significance (p < .05). All inter-factor correlations can be found in Table 3.3. Similarly to the standardization sample, items belonging to the same factor tended to be correlated more strongly than between items of different factors; however, Emotional Control tended to have the weakest inter-item correlations and contained the only pair of items within the same factor to be non-significantly correlated (items 82 and 86). This is also reflected in the low reliability of Emotional Control in this sample.

Confirmatory factor analysis (CFA)

The a priori four-factor model of executive behaviours (Model 4) was evaluated using confirmatory factor analysis (CFA). Model 4 was evaluated based on fit to the observed data and comparisons to 3 other alternative models. The alternative models were selected based on theoretical variations consistent with current conceptualizations of executive functioning and reflected in previous evaluations on these models done by Garcia-Barrera et al. (2011). Model 1 is a one-factor model and consists of all 25 items loading onto a single unitary executive function latent construct. Model 2 is a two-factor model and consists of a Problem Solving factor and a Behavioural Self-Regulation factor with 6 and 19 items loading onto the two factors, respectively. Model 3 is a three-factor model and consists of a Problem Solving factor, Attentional Control factor, and a combined Behavioural-Emotional Control factor with 6 items loading onto the former two and 13 items loading onto the combined factor. Examples of all models can be found in Figures 1.1-1.4.

Study 1. For the standardization sample, every model converged normally and fit indices are reported in Table 5.1. Models 1-4 demonstrated increasingly better model fit in relation to increasing model complexity. Large CFI and TFI values were observed for all models and showed excellent fit to the data (CFI > .95, TLI > .95) with Model 4 demonstrating the best overall fit (CFI = .990, TLI = .989). All models had significant χ^2 values (p < .000); due to the large sample size, this was expected. As model complexity increased, χ^2 values decreased with Model 4 demonstrating the smallest χ^2 and therefore the best fit (χ^2 = 1250.344). All models except for Model 1 had RMSEA below the optimum cut-off criterion of .05 with Model 4 having the smallest and therefore best, observed value (RMSEA = .037). These results indicate that the BASC-2 executive behaviour screener (Garcia-Barrera et al., 2011) and four-factor model of executive behaviours is replicable using the BASC-2 PRS-A.

Study 2. For the hockey sample, every model converged normally and fit indices are also reported in Table 5.1. Similarly to the standardization sample, models 1-4 demonstrated increasing fit in relation to model complexity. All models showed excellent fit to the data (CFI > .95, TLI > .95) despite weak reliability and correlations with the Emotional Control factor. Model 4 demonstrated the best fit to the data (χ^2 = 351.043) and smallest RMSEA (RMSEA = .026). All models showed an RMSEA below the optimum cut-off criterion indicating that the model continues to be replicable within a population of adolescent athletes, some with a history of concussion.

Individual item factor loadings for Model 4 are contained in Table 4 for both the samples. Factor loadings represent how strong an association is between a particular item and its parent factor with squared factor loadings (R^2) indicating the proportion of variance the factor explains for that particular item. Standardized factor loadings greater than .3 are considered to be fairly strong, factor loadings greater than .7 are considered to be very strong, and factor loadings of 1.0 are considered optimal but unlikely to occur in data collected from a real-world population (Furr & Bacharach, 2014).

Study 1. For the standardization sample, standardized factor loadings for Model 4 ranged from .498 to .812 collectively. For Problem Solving, factor loadings ranged from .625 to .722. For Attentional Control, factor loadings ranged from .703 to .812. For Behavioural Control, factor loadings ranged from .498 to .746. Emotional Control factor loadings ranged from .526 to .686. Overall, R^2 values ranged from .248 to .660. The overall strength of the factor loadings demonstrates the quality of selection for the individual indicators and explains the excellent fit of the model to the data.

Study 2. For the hockey sample, standardized loadings ranged from .252 to .762 as a whole. For Problem Solving, standardized loadings ranged from .508 to .668. For Attentional Control, factor loadings ranged from .608 to .762. Behavioural Control factor loadings ranged from .252 to .714. Emotional Control loadings ranged from .382 to .543. Overall, R^2 values ranged from .063 to .580. Factor loadings in general were smaller than in the standardization sample indicating weaker associations between items and their parent factors.

Invariance testing

In order to ascertain measurement invariance of the four-factor model across dichotomous groupings (e.g. sex), a series of models were tested with everything except factor structure initially held constant and subsequent models releasing constraints in a step-wise manner at the metric, scalar, and latent mean levels if invariance at the previous level was observed. For the standardization sample from Study 1, only measurement invariance between the sexes was tested in this manner and model fit indices can be found in Table 5.3. All models were deemed to show a lack of invariance between males and females using the χ^2 statistic. However, as χ^2 is sensitive to large sample sizes, it is more informative to use ΔCFI and ΔRMSEA to determine invariance between ratings of males and females. Using a criterion of less than .01 for ΔCFI and ΔRMSEA, it is apparent that configural, metric, and scalar invariance are demonstrated but not latent mean invariance between males and females indicating that there are differences in the actual latent or unobserved levels of executive behaviours between the sexes. For a visual representation of these differences, Figure 2.1 shows the mean level scores of males and females. Additional invariance testing was conducted between the two samples and model fit indices can also be found in Table 5.3. Like with sex, all models showed a lack of invariance between the two samples using the χ^2 statistic but based on the aforementioned criterion for ΔCFI and ΔRMSEA, configural, metric, and scalar invariance is demonstrated but not latent mean invariance between the two samples. This indicates that there are actual differences in the latent or unobserved levels of executive behaviours between the standardization sample and the elite adolescent hockey players, which can be seen in Figure 2.2.

Multiple inputs multiple causes (MIMIC) models

For the standardization sample, MIMIC models for age and SES were generated via nested-model comparisons with age or SES acting as a covariate for each executive behaviour factor and age/SES-by-factor interactions being calculated above and beyond the information captured by each model of the four factors separately. For the hockey sample, identically structured MIMIC models were generated using the number of previous number of concussions as the covariate for each executive factor and interactions being calculated in the same way as previously mentioned. Figure 3 gives an example of the general structure of the MIMIC models using Problem Solving as a factor and age as covariate alongside an interaction term. Bold lines represent significant loadings. Non-significant factor loadings or dotted lines on the covariate (age or SES) indicate that an item does not demonstrate uniform differential item functioning (DIF) or alternatively, show scalar invariance. Non-significant factor loadings on the interaction term indicate that an item does not demonstrate non-uniform DIF or alternatively, shows metric invariance. As MIMIC models that include interaction terms have a tendency to inflate Type 1 error (Woods & Grimm, 2011), corrected significance values were based on the permutation distribution by computing a typically recommended minimum of 10000 random permutations (Legendre & Legendre, 1998, pp. 26). Unadjusted p-values for the individually tested parameters and adjusted p-values simultaneously testing both parameters can be found in Tables 6.1-6.4.

After correcting for Type 1 error, Attentional Control and Emotional Control showed no signs of uniform and non-uniform DIF with respect to age. Problem Solving did not show non-uniform DIF on all items with items 93 and 127 showing uniform DIF (lacking scalar invariance) with respect to age ($p < .05$). Behavioural Control showed no signs of non-uniform DIF on all items with item 80 showing uniform DIF with respect to age ($p < .01$). Only Emotional Control demonstrated no signs of uniform and non-uniform DIF for all items with respect to SES. Problem Solving did not demonstrate non-uniform DIF for all items with items 56, 111, and 127 indicating uniform DIF ($p < .01$) with respect to SES. Attentional Control showed non-uniform DIF for item 136 ($p < .05$) with respect to SES. Item 76 showed evidence of both uniform and non-uniform DIF ($p < .001$) with regards to SES. Behavioural Control showed uniform DIF in item 33 ($p < .01$) and both uniform and non-uniform DIF for item 70 ($p < .001$) with respect to SES. Figures 2.3 and 2.4 depict the mean level differences between different ages and different levels of SES, respectively. In relation to concussions, all factors did not show uniform or non-uniform DIF.

T-scores and Z-scores

One of the main goals of this study was to produce norms for the BASC-2 PRS-A executive behaviour screener and these unadjusted norms can be found for each factor in Tables 7.1-7.4. Tables that require adjustment based on SES, age, or sex are denoted as such. All factor norms must be adjusted for sex and all factor norms except for Emotional Control must be adjusted for age and SES.

Longitudinal Subset

A total of 36 individuals in the hockey sample had baseline, 1-week post-concussion follow-up, and 3-month follow-up BASC-2 PRS-A ratings completed and this subset formed a clinical sample of individuals who had suffered concussions after a baseline test period. Due to considerations of power, no further statistical analyses were conducted on this group but a visual inspection of the changes to factor scores over time is presented in Figures 4.1-4.4. The thick black line indicates the average trajectory of change in factor scores and the blue and red horizontal lines represent elevated levels of clinical concern and risk, respectively. Most individuals within this subset did not reach a level of clinical concern for any of the factors and for those that did, they were already within that elevated region prior to any recent concussions at baseline measurement.

Discussion

Overall, correlations and reliability for the scale were weaker for the hockey players than the standardization sample. This can be partially attributed to the fact that the standardization sample is a larger and more demographically representative group than elite adolescent hockey players, the majority of whom were male. Within both samples, inter-item correlations were strongest for items that fell within the same factor scale providing support for the theoretically based item selection process as the items are more related to one another than to items of a different scale. Inter-factor correlations within the standardization sample were similar to those found in other studies (Garcia-Barrera et al., 2011). Reliabilities for the standardization sample were similar to other studies, which ranged from .805 to .890 in the original BASC-2 study (Garcia-Barrera et al., 2011) reflecting the importance of using a demographically representative sample for developing this screener. This is further supported by the fact that both the inter-factor correlations and factor reliabilities for the hockey sample were lower and were more similar to studies that used smaller, less representative samples (Duggan et al., 2016). However, this lower reliability and inter-factor correlation may be indicative of a more highly developed and fractionated (specialized) executive function structure as the hockey sample had lower overall factor scores, which means that they were rated by their parents as having fewer problems. This result may point to a positive effect of sports participation on executive function though further research must be completed to explore the robustness and magnitude of these reported differences.

Unidimensional and multidimensional models of the executive behaviour screener were tested with confirmatory factor analysis, which indicated that the four-factor model (Model 4) best fit the data in both samples. While all other models converged normally and surpassed strict cut-offs for model fit indices (except for Model 1 for the standardization sample), the four-factor model showed the most improvements over the other models. In the transition from the three-factor model (Model 3) to the four-factor model (Model 4), where Behavioural and Emotional Control are split apart, the ΔCFI was relatively small compared to previous work done on the BASC Teacher Rating Scale – Children (BASC-TRS-C, ΔCFI = -.012; Garcia-Barrera et al., 2011) and BASC-2 Self-Report of Personality – College (BASC-2 SRP-C, ΔCFI = -.100; Duggan et al., 2016). This comparison may indicate that Behavioural and Emotional Control may not be as differentiated from one another within this sample and age range. At the same time, model fit was extremely high with Model 3 (CFI = .986), which would not allow for a large change in fit indices even if Behavioural and Emotional control were fairly distinct. Model 4 (CFI = .990) having a near perfect fit, was a significantly better fit than Model 3 while also being the most theoretically supported. The strength of the four-factor model and relevant fit indices is in line with other studies using this approach (Duggan et al., 2016; Garcia-Barrera et al., 2011, 2013) and provides greater support for the robustness of the four-factor model given the level of stability of this measure within adolescence and across the two samples.

Invariance testing between males and females demonstrated that the executive behaviour screener shows configural, metric, and scalar invariance as is consistent with previous studies (Duggan et al., 2016; Garcia-Barrera et al., 2011); however, latent mean invariance was never assessed in the previous work and in our current study, we did not find latent mean invariance. This new finding indicates that while factor structure, factor loadings, and indicator means are similar, adolescent males and females may have differences in their underlying levels of their executive behaviours (as seen in Figure 2.1). Latent executive functioning differences between the sexes may be due to different neurodevelopmental trajectories within adolescence (Garcia-Barrera et al., 2013; Lax et al., 2015; Tamnes et al., 2010). Additionally, within the BASC-2 itself, several of the scales demonstrate sex differences. Males show higher raw scores in Hyperactivity, Aggression, Attention Problems and Learning Problems and females show higher raw scores in Social Skills, Leadership, Study Skills, and Functional Communication (Reynolds & Kamphaus, 2004). Many of the items in the executive screener were drawn from these original scales and the sex differences may also be a reflection of that. There also may be a role of different socialization processes over this age period that causes males or females to behave differently in response to certain life events (Crone, 2009). Interestingly, a similar result was found during invariance testing between the two samples with configural, metric, and scalar invariance being demonstrated but not latent mean invariance. Hockey players were found to have significantly lower latent mean values than the individuals in the standardization sample (seen in Figure 2.2). It is possible that sport participation and particularly, open sport participation lends itself to general cognitive improvements that facilitate the development of good executive function and this has been shown cumulative support in the literature (Best, 2010; Russo et al., 2010; Jacobson & Matthaeus, 2014; Wang et al., 2013). Another possible explanation is that those play sports at a high-level already have superior EF and may be self-selecting into dynamic and cognitively challenging sports. While there is no research examining EF-related self-selection into sports, there is research indicating that children and adolescents who have high levels of motor control go on to have increased participation in sports and physical fitness (Barnett, Morgan, van Beurden & Beard, 2008; Cattuzzo et al., 2014; Stodden, True, Langendorfer & Gao, 2013). Furthermore, tasks that train complex motor control have been shown to improve performance on executive function tasks (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribiero, & Tidow, 2008), which would suggest that there might be a bidirectional relationship between executive control processes and sports participation. Though we do not have SES data on the hockey players, another possible explanation is that as these individuals participate in a relatively expensive sport that requires a great deal of time commitment and family investment, these individuals may have relatively high SES compared to the standardization sample. It is known that SES is a factor that can influence cognitive functioning positively due to increased exposure to environmental stimuli, better nutrition, and decreased stress (Hackman et al., 2010; Ursache & Noble, 2016a). Ultimately, the differences between the two samples may be due to differences in SES, sports participation, or a combination of the two. Further research is needed to explore the extent of these differences and whether these differences continue to hold over time.

In regards to the MIMIC models examining uniform and non-uniform DIF, age failed to demonstrate non-uniform DIF across all items and uniform DIF across most items on the executive behaviour screener, indicating that all items function similarly but some items were more discriminating for parental evaluations of executive behaviours for certain ages. Two of the items related to Problem Solving showed uniform DIF (items 93 and 127) as did one item related to Behavioural Control (item 80). These items may be more attuned to changes in parental observations in Problem Solving ability over the course of adolescent development. No items related to Attentional Control or Emotional Control showed uniform DIF. This points to age-specific developmental trajectories within adolescence specific to goal setting, planning, and behavioural inhibitory processes that is consistent with previous literature examining executive function and brain development (Huizinga et al., 2006; Lax et al., 2015; Leon-Carrion et al., 2004; Tamnes et al., 2010). Figure 2.3 depicts mean factor scores for each age with a noticeable decrease in reported executive behaviour problems over time except at ages 19-21 for some of the factors. This is likely due to the low numbers of individuals in the 19-21 year old range making up less than 2% of the sample collectively.

Relative to age, different levels of SES seem to cause the greater numbers of items to demonstrate uniform and non-uniform DIF. Mean factor scores are shown in Figure 2.4 with increasing levels of SES showing lower levels of reported executive behaviour problems. This may be indicative of a potentially large influence of SES on ratings of executive behaviour as is consistent with previous literature examining the effects of SES on cognitive function. At the same time, no direct statistical comparisons of mean differences can be inferred as both SES and age demonstrated uniform or non-uniform DIF and therefore did not show scalar or metric invariance. As such, parents with different levels of education may interpret items differently and certain items may simply be better items in general at discriminating between executive behaviours for individuals with higher or lower levels of executive behaviour dysfunction. This result may also help explain the differences in scores between the hockey and standardization samples although scalar invariance was demonstrated between the two samples. Having an increasing number of concussions prior to baseline did not show any signs of uniform or non-uniform DIF on any items. This indicates that a previous history of concussions is not a relevant influence in determining uniform and non-uniform DIF for the screener. Most individuals who suffer concussions have all of their symptoms resolve over time (Carroll et al., 2014; Karr et al., 2014b) and as the sample of hockey players were considered healthy at baseline, this may explain this result that there were no indications of DIF found.

Emotional Control consistently showed the weakest factor loadings relative to the other factors and this may indicate a relative developmental weakness in emotional regulation within adolescence. This result has been observed in previous work with other versions of the BASC-2 executive behaviour screener with females showing better Emotional Control than males but did not show differences in the rate of developing Emotional Control over time (Garcia-Barrera et al., 2013). Interestingly, despite this relative weakness in factor loadings, Emotional Control was the only factor that did not demonstrate uniform or non-uniform DIF across age, SES, and number of previous concussions sustained. This may add to the idea that the ability to regulate your emotions may be developing at a similar rate for all adolescents regardless of age, SES, and history of concussion. Further research is necessarily to track the unique development of Emotional Control across the lifespan.

In this context of variations in factor invariance, uniform and non-uniform DIF, the T-score conversion tables provided are a starting point in developing robust norms for use in clinical populations. There is evidence for latent mean differences between males and females as well as evidence for age and SES likely being influential in determining factor scores on the executive behaviour screener. For future research, examinations of item characteristic curves must be undertaken to understand the full range of influence of age and SES on this screener and appropriate adjustments should be made to interpretations of the T-score tables as necessary.

Upon close visual inspection of Figures 4.1-4.4, it appears that for the small subset of individuals who suffered a concussion at some point during the data collection process, on average did not suffer significant impacts on their executive behaviour ratings. Most of these individuals never reached a level of clinical concern, even when recently concussed. This lack of behavioural evidence for the effects of concussion is consistent with much of the literature (Brooks et al., 2013) and this executive behaviour screener may not be sensitive enough to detect changes in decreased levels of executive function due to concussion, as is common for behavioural measures such as rating scales. The inability for behavioural rating scales to pick up changes in executive function due to concussion may be due to the rating scales tapping into different levels of executive function (Toplak et al., 2013) that are relatively preserved from damage. At the same time, the hockey players showed lower executive behaviour scores on average than the standardization sample, which may partially explain why no clinical concerns would be raised for these players despite receiving concussions. Furthermore, there may be a protective role of sports participation that masks the effects of concussion on executive behaviour ratings. Further studies on larger samples must be conducted to examine the potential for cognitive buffering against concussion due to sports participation.

Clinical Implications

As norms for this executive behaviour screener have been provided, it is our hope that this screener be implemented in settings where the assessment of executive functions in day-to-day life. When using the norms, contextual factors like age, SES, and sex must be kept in mind. For example, if one is assessing a 12-year-old male with low SES and he receives a T-score of 65 (indicating clinical concern) on all factors, that might be viewed as relatively normal given his age, SES, and sex. If a 17-year-old female with high SES were to receive similar scores, that may be indicative of an actual clinical concern that warrants further investigation as an individual in that demographic generally should have far lower T-scores. As with most assessment tools, good clinical judgment is necessary to draw accurate conclusions from the results.

In summary, the current study was the first to successfully derived an executive behaviour screener from the BASC-2 PRS-A and was the first to provide evidence for latent mean sex differences for factor scores. It was also the first to show that SES-related metric invariance was not observed. Additionally, it showed that age and SES-related scalar invariances were not observed. It was the first to apply this screener to a population of athletes and results showed that elite adolescent hockey players have lower executive behaviour scores than the standardization sample, indicating fewer behavioural issues overall. The psychometric properties of this screener are reliable and it demonstrates an excellent overall model fit. There are a couple of factors that may affect the interpretations of the results and invite us to exercise caution during future implementation of this measure. First, it is still unclear as to the mechanism for differences in executive function between the hockey and standardization sample. We were unable to separate sport participation with SES in our analysis. Second, the T-scores generated in this study are incomplete in the sense that they must be viewed in the context of age, sex, and SES. Overall, the results of this study lend support and expand upon the foundation laid by Garcia-Barrera et al.'s (2011) executive behaviour screener. These results contribute to our understanding of how executive functions develop in adolescence as well providing important information on the sensitivity of behavioural measures when assessing for executive function change due to concussion. Though future research and development is still needed, this study provides strong support for an executive behaviour screener within adolescence.

Table 1: *Demographics*

	Standardization Sample	Hockey Sample
Sample Size	2,722	479
Age (M ± SD)	14.79 ± 2.00	15.01 ± 1.20
	Age Distribution (% of sample)	
12	476 (17.49)	4 (.84)
13	440 (16.16)	47 (9.81)
14	328 (12.05)	116 (24.22)
15	396 (14.55)	142 (29.65)
16	398 (14.62)	111 (23.17)
17	448 (16.46)	59 (12.32)
18	199 (7.31)	N/A
19	28 (1.03)	N/A
20	6 (.22)	N/A
21	3 (.11)	N/A
	Sex Distribution (% of sample)	
Female	1,432 (52.61)	65 (13.57)
Male	1,290 (47.39)	414 (86.43)

Table 2: *Item-level Descriptives*

	Standardization					Hockey				
Item	N	M	SD	Skewness	Kurtosis	N	M	SD	Skewness	Kurtosis
Problem Solving										
37	2713	2.43	.87	-.07	- .73	479	1.95	.74	.17	-.91
56	2719	2.14	.91	.21	- .98	478	2.06	.77	.08	.90
77	2715	2.21	.85	.05	- .83	479	1.94	.66	.20	-.24
93	2719	2.42	.96	-.08	- 1.00	478	2.26	.82	-.11	-.87
111	2716	2.14	.91	.35	- .73	478	1.84	.70	.41	-.27
127	2717	2.28	.79	-.05	- .66	479	1.97	.63	.07	-.29
Attentional Control										
5	2713	1.94	.82	.29	- 1.00	478	1.82	.67	.23	-.83
35	2716	1.78	.87	.98	.26	477	1.71	.66	.65	.48
65	2715	1.95	.83	.29	- 1.03	479	1.83	.67	.21	-.79
76	2720	1.89	.81	.34	- 1.04	477	1.65	.64	.51	-.45
106	2719	2.13	.85	.02	- 1.08	478	2.05	.70	-.03	-.88
136	2715	1.95	.86	.75	.06	479	1.75	.68	.64	.36
Behavioural Control										
20	2716	1.96	.71	.77	1.11	477	1.79	.54	.12	1.13
33	2719	1.73	.77	.63	- .65	478	1.56	.59	.55	-.29
45	2719	1.50	.72	1.48	1.91	478	1.25	.47	1.63	1.69
70	2718	1.28	.53	1.99	4.32	479	1.13	.36	**2.91**	**10.39**
73	2717	1.68	.63	.68	.87	479	1.48	.52	.41	-.65
75	2717	1.30	.57	1.98	3.94	478	1.12	.33	**2.48**	4.79
80	2716	1.82	.71	.79	1.02	479	1.68	.52	-.23	-.81
135	2718	1.35	.57	1.63	2.79	478	1.18	.39	1.79	1.55
Emotional Control										
18	2720	1.15	.88	.10	- 1.01	478	1.85	.72	.33	-.71
61	2703	1.97	.83	.33	- .81	479	1.73	.67	.45	-.42
68	2719	1.79	.75	.84	.66	479	1.68	.62	.51	.13
82	2719	1.86	.75	.75	.59	478	1.48	.55	.52	-.86
86	2719	1.07	.91	.28	- .99	478	2.13	.79	.04	-.84

Table 3.1: *Inter-Item Correlation - Standardization*

	Correlations																								
	Problem Solving						Attentional Control						Behavioural Control								Emotional Control				
Item	37	56	77	93	111	127	5	35	65	76	106	136	20	33	45	70	73	75	80	135	18	61	68	82	86
37	1																								
56	.47	1																							
77	.41	.48	1																						
93	.44	.50	.43	1																					
111	.49	.51	.43	.46	1																				
127	.53	.47	.44	.44	.51	1																			
5	.46	.51	.43	.52	.51	.51	1																		
35	.37	.45	.37	.45	.42	.38	.58	1																	
65	.48	.51	.43	.53	.55	.48	.70	.51	1																
76	.45	.47	.42	.49	.50	.48	.64	.48	.67	1															
106	.44	.49	.41	.50	.46	.44	.63	.51	.63	.58	1														
136	.37	.44	.36	.44	.41	.38	.55	.67	.49	.47	.47	1													
20	.34	.39	.27	.39	.35	.31	.47	.49	.45	.44	.48	.50	1												
33	.32	.38	.29	.36	.38	.35	.46	.38	.44	.43	.41	.36	.40	1											
45	.34	.36	.32	.36	.36	.29	.45	.48	.43	.42	.39	.46	.49	.38	1										
70	.25	.23	.19	.23	.22	.20	.30	.29	.28	.30	.25	.26	.31	.28	.34	1									
73	.25	.28	.18	.28	.25	.22	.37	.39	.37	.33	.38	.35	.46	.37	.42	.34	1								
75	.29	.31	.27	.31	.34	.29	.44	.43	.41	.40	.35	.39	.41	.37	.53	.39	.39	1							
80	.25	.29	.19	.32	.25	.25	.38	.41	.37	.37	.36	.42	.44	.26	.40	.31	.38	.39	1						
135	.27	.30	.21	.29	.29	.24	.38	.38	.39	.38	.34	.36	.40	.33	.40	.43	.37	.42	.41	1					
18	.37	.38	.39	.37	.38	.37	.46	.37	.47	.46	.42	.36	.30	.34	.37	.25	.31	.35	.29	.29	1				
61	.41	.40	.39	.35	.43	.40	.47	.35	.46	.46	.40	.35	.32	.33	.36	.23	.27	.35	.26	.27	.58	1			
68	.23	.22	.22	.22	.23	.21	.29	.32	.29	.30	.27	.36	.35	.25	.37	.29	.33	.38	.32	.29	.36	.33	1		
82	.28	.26	.29	.28	.30	.27	.33	.37	.32	.32	.29	.40	.35	.27	.41	.29	.33	.39	.34	.28	.40	.39	.53	1	
86	.39	.43	.42	.35	.39	.37	.38	.32	.39	.39	.39	.32	.27	.29	.30	.21	.19	.27	.19	.23	.35	.38	.23	.24	1

All correlations are significant with p-values < .0000

Table 3.2: *Inter-Item Correlation – Hockey Sample*

												Correlations													
			Problem Solving						Attentional Control									Behavioural Control					Emotional Control		
Item	37	56	77	93	111	127	5	35	65	76	106	136	20	33	45	70	73	75	80	135	18	61	68	82	86
37	1																								
56	.33**	1																							
77	.33**	.30**	1																						
93	.29**	.45**	.33**	1																					
111	.32**	.43**	.37**	.44**	1																				
127	.38**	.38**	.32**	.37**	.44**	1																			
5	.37**	.42**	.34**	.47**	.38**	.35**	1																		
35	.25**	.35**	.27**	.41**	.32**	.27**	.49**	1																	
65	.29**	.41**	.26**	.40**	.38**	.33**	.50**	.38**	1																
76	.32**	.41**	.32**	.41**	.45**	.36**	.50**	.37**	.62**	1															
106	.31**	.46**	.34**	.50**	.47**	.40**	.55**	.46**	.59**	.58**	1														
136	.20**	.38**	.29**	.43**	.35**	.30**	.43**	.59**	.37**	.37**	.44**	1													
20	.20**	.30**	.14*	.27**	.23**	.25**	.31**	.38**	.31**	.27**	.32**	.37**	1												
33	.28**	.31**	.24**	.32**	.34**	.39**	.43**	.35**	.45**	.40**	.41**	.35**	.43**	1											
45	.20**	.14*	.18**	.24**	.27**	.22**	.23**	.26**	.19**	.20**	.21**	.32**	.31**	.29**	1										
70	.19**	.10^{+}	.11^{+}	.08	.07	.12*	.08	.11^{+}	.11^{+}	.15*	.16**	.08	.17**	.15**	.15**	1									
73	.24**	.20**	.12*	.16**	.17**	.22**	.25**	.22**	.32**	.24**	.25**	.21**	.35**	.39**	.26**	.24**	1								
75	.13*	.06	.05	.12*	.20**	.10^{+}	.11^{+}	.19**	.17**	.20**	.15**	.21**	.25**	.20**	.30**	.22**	.23**	1							
80	.19**	.12^{+}	.10^{+}	.16**	.17**	.09^{+}	.21**	.24**	.24**	.25**	.22**	.22**	.20**	.20**	.15*	.16**	.26**	.15*	1						
135	.14*	.14*	.25^{+}	.17**	.16**	.17**	.14*	.15**	.21**	.24**	.24**	.19**	.26**	.23**	.27**	.32**	.28**	.24**	.21**	1					
18	.34**	.30**	.33**	.28**	.29**	.22**	.31**	.25**	.34**	.32**	.24**	.18**	.15*	.29**	.20**	.06	.22**	.07	.13*	.17**	1				
61	.26**	.29**	.16**	.23**	.33**	.16**	.29**	.18**	.31**	.32**	.33**	.13*	.10^{+}	.19**	.14*	-.02	.13*	.09^{+}	.06	.05	.28**	1			
68	.10^{+}	.10^{+}	.18**	.14*	.17**	.20**	.16**	.20**	.22**	.15**	.17**	.21**	.18**	.20**	.20**	.14*	.22**	.22**	.10^{+}	.18**	.22**	.21**	1		
82	.18**	.15*	.18**	.19**	.16**	.19**	.16**	.20**	.21**	.19**	.18**	.24**	.21**	.12*	.25**	.07	.27**	.16**	.20**	.23**	.32**	.18**	.33**	1	
86	.29**	.28**	.31**	.33**	.32**	.33**	.29**	.24**	.25**	.30**	.32**	.22**	.12*	.24**	.24**	.09	.13*	.16**	.06	.11^{+}	.19**	.25**	.13*	.07	1

** = p < .001, * = p < .01, $^{+}$ = p <.05

Table 3.3: *Factor-level correlations*

Factors	Standardization Sample				Hockey Sample			
	PS	AC	BC	EC	PS	AC	BC	EC
Problem Solving	1				1			
Attentional Control	.76	1			.70	1		
Behavioural Control	.58	.72	1		.48	.57	1	
Emotional Control	.64	.66	.63	1	.57	.52	.44	1

*All correlations are significant to p < .0001

Table 4: *Factor Loadings and Internal Consistency*

	Standardization				Hockey			
Item	Unstandardized factor loadings	SE	Standardized factor loadings	R^2	Unstandardized factor loadings	SE	Standardized factor loadings	R^2
	Problem Solving (α = .84)				Problem Solving (α = .77)			
Item 37	1.000		.676	.458	1.000		.528	.279
Item 56	1.123	.017	.722	.522	1.125	.063	.632	.399
Item 77	.895	.015	.625	.390	.830	.047	.508	.258
Item 93	1.149	.018	.703	.495	1.399	.069	.668	.446
Item 111	1.108	.017	.719	.517	1.150	.058	.647	.418
Item 127	.904	.014	.669	.448	.949	.050	.596	.356
	Attentional Control (α = .89)				Attentional Control (α = .85)			
Item 5	1.000		.812	.660	1.000		.721	.520
Item 35	.942	.013	.723	.523	.828	.037	.608	.369
Item 65	.998	.013	.800	.640	.961	.040	.705	.497
Item 76	.938	.012	.766	.587	.973	.040	.742	.551
Item 106	.937	.012	.738	.544	1.093	.044	.762	.580
Item 136	.902	.013	.703	.494	.865	.039	.620	.384
	Behavioural Control (α = .85)				Behavioural Control (α = .72)			
Item 20	1.000		.746	.556	1.000		.619	.383
Item 33	.919	.016	.640	.409	1.260	.066	.714	.510
Item 45	.966	.017	.712	.506	.731	.046	.524	.275
Item 70	.491	.010	.498	.248	.275	.026	.252	.063
Item 73	.721	.013	.612	.375	.853	.050	.544	.296
Item 75	.715	.013	.670	.449	.347	.027	.357	.128
Item 80	.812	.015	.616	.379	.610	.042	.400	.160
Item 135	.652	.012	.608	.369	.484	.033	.416	.173
	Emotional Control (α = .75)				Emotional Control (α = .58)			
Item 18	1.000		.685	.470	1.000		.543	.295
Item 61	.934	.015	.686	.470	.807	.051	.477	.228
Item 68	.648	.012	.526	.277	.604	.043	.382	.146
Item 82	.714	.013	.579	.335	.582	.039	.420	.176
Item 86	.873	.015	.582	.338	1.003	.061	.502	.252

Table 5.1: *Model Variation Analysis – Standardization Sample*

Model	DWLS χ^2	$\Delta\chi^2$ ($p < .05$)	df	CFI (.95)	ΔCFI	TLI (.95)	RMSEA (.06)	ΔRMSEA
Model 1: 25 items, 1 factor	2294.083		275	.980		.978	.053	
Model 2: 25 items, 2 factors	1947.239	346.844 (0.000)	274	.983	.003	.982	.048	- .005
Model 3: 25 items, 3 factors	1620.480	326.759 (0.000)	272	.986	.003	.985	.044	- .004
Model 4: 25 items, 4 factors	1250.344	370.136 (0.000)	269	.990	.004	.989	.037	- .007

Table 5.2: *Model Variation Analysis – Hockey Sample*

Model	DWLS χ^2	$\Delta\chi^2$ ($p < .05$)	df	CFI (.95)	ΔCFI	TLI (.95)	RMSEA (.06)	ΔRMSEA
Model 1: 25 items, 1 factor	495.740		275	.976		.974	.042	
Model 2: 25 items, 2 factors	471.902	23.838 (0.000)	274	.979	.003	.977	.040	- .002
Model 3: 25 items, 3 factors	416.301	55.601 (0.000)	272	.985	.006	.983	.034	- .006
Model 4: 25 items, 4 factors	351.043	65.258 (0.000)	269	.991	.004	.990	.026	- .008

Table 5.3: *Analysis of Measurement Invariance*

Model	DWLS χ^2	$\Delta\chi^2$ (p)	df	CFI	ΔCFI	TLI	RMSEA	ΔRMSEA
Measurement invariance for male and female groups								
Step 1: Configural	1351.913		538	.992		.991	.034	
Step 2: Metric	1579.844	227.931 (.000)	559	.989	.003	.989	.037	.003
Step 3: Scalar	1715.085	135.241 (.000)	580	.988	.001	.988	.039	.002
Step 4: Latent Mean	2786.554	1071.469 (.000)	584	.977	.011	.977	.061	.015
Measurement invariance between samples								
Step 1: Configural	1601.388		538	.990		.989	.036	
Step 2: Metric	2032.366	430.978 (.000)	559	.986	.004	.985	.041	.005
Step 3: Scalar	2252.938	220.572 (.000)	580	.985	.001	.984	.043	.002
Step 4: Latent Mean	3271.979	1019.041 (.000)	584	.975	.010	.975	.055	.012

Model	DWLS χ^2	$\Delta\chi^2$ ($p<.05$)	df	CFI	ΔCFI (.01)	TLI	RMSEA	ΔRMSEA (.01)
Measurement invariance between samples								
Step 1: Configural	1601.388		538	.990		.989	.036	
Step 2: Metric	2032.366	430.978 (.000)	559	.986	.004	.985	.041	.005
Step 3: Scalar	2252.938	220.572 (.000)	580	.985	.001	.984	.043	.002
Step 4: Latent Mean	3271.979	1019.041 (.000)	584	.975	.010	.975	.055	.012

Model	DWLS χ^2	$\Delta\chi^2$ ($p<.05$)	df	CFI	ΔCFI (.01)	TLI	RMSEA	ΔRMSEA (.01)
Measurement invariance for male and female groups								
Step 1: Configural	1351.913		538	.992		.991	.034	
Step 2: Metric	1579.844	227.931 (.000)	559	.989	.003	.989	.037	.003
Step 3: Scalar	1715.085	135.241 (.000)	580	.988	.001	.988	.039	.002
Step 4: Latent Mean	2786.554	1071.469 (.000)	584	.977	.011	.977	.061	.015

Table 6.1: *Problem Solving – Univariate tests for age, SES, and interaction-terms*

	χ^2	df	p-value	Adjusted p-value
Item 37				
Age	2.621	1	.105	.656
Age x Problem Solving	.433	1	.511	
SES	.524	1	.469	.988
SES x Problem Solving	.521	1	.470	
Item 56				
Age	4.074	1	.044	.458
Age x Problem Solving	.156	1	.693	
SES	12.224	1	.000	.008
SES x Problem Solving	.005	1	.946	
Item 77				
Age	.103	1	.748	1.000
Age x Problem Solving	.106	1	.744	
SES	.526	1	.468	.986
SES x Problem Solving	.563	1	.453	
Item 93				
Age	11.386	1	.001	.010
Age x Problem Solving	.908	1	.341	
SES	8.579	1	.003	.052
SES x Problem Solving	.173	1	.678	
Item 111				
Age	.574	1	.449	.953
Age x Problem Solving	1.055	1	.304	
SES	10.968	1	.001	.008
SES x Problem Solving	1.150	1	.284	
Item 127				
Age	9.259	1	.002	.036
Age x Problem Solving	.374	1	.541	
SES	16.886	1	.000	.001
SES x Problem Solving	.512	1	.474	

Table 6.2: *Attentional Control – Univariate tests for age, SES, and interaction-terms*

	χ^2	df	p-value	Adjusted p-value
Item 5				
Age	4.741	1	.029	.203
Age x Attentional Control	1.226	1	.268	
SES	.034	1	.854	.987
SES x Attentional Control	.994	1	.319	
Item 35				
Age	.001	1	.979	.999
Age x Attentional Control	.444	1	.505	
SES	4.637	1	.031	.098
SES x Attentional Control	3.374	1	.066	
Item 65				
Age	.312	1	.576	.999
Age x Attentional Control	.268	1	.605	
SES	1.751	1	.186	.722
SES x Attentional Control	1.180	1	.277	
Item 76				
Age	1.034	1	.309	.357
Age x Attentional Control	3.684	1	.055	
SES	13.793	1	.000	.000
SES x Attentional Control	4.755	1	.029	
Item 106				
Age	.021	1	.885	.999
Age x Attentional Control	.415	1	.520	
SES	7.764	1	.005	.100
SES x Attentional Control	.106	1	.744	
Item 136				
Age	1.016	1	.313	.987
Age x Attentional Control	.000	1	.984	
SES	.265	1	.607	.031
SES x Attentional Control	10.020	1	.002	

Table 6.3: *Behavioural Control – Univariate tests for age, SES, and interaction-terms*

	χ^2	df	p-value	Adjusted p-value
Item 20				
Age	.831	1	.362	.608
Age x Behavioural Control	4.313	1	.038	
SES	6.113	1	.013	.462
SES x Behavioural Control	.321	1	.571	
Item 33				
Age	1.900	1	.168	.938
Age x Behavioural Control	.776	1	.378	
SES	18.643	1	.000	.005
SES x Behavioural Control	3.643	1	.056	
Item 45				
Age	2.934	1	.087	.678
Age x Behavioural Control	1.680	1	.195	
SES	3.540	1	.060	.142
SES x Behavioural Control	7.083	1	.008	
Item 70				
Age	2.036	1	.154	.551
Age x Behavioural Control	3.471	1	.062	
SES	44.325	1	.000	.000
SES x Behavioural Control	34.527	1	.000	
Item 73				
Age	8.414	1	.004	.256
Age x Behavioural Control	0.074	1	.786	
SES	1.349	1	.245	.736
SES x Behavioural Control	3.041	1	.081	
Item 75				
Age	.208	1	.649	.903
Age x Behavioural Control	3.037	1	.081	
SES	.583	1	.445	.974
SES x Behavioural Control	1.596	1	.206	
Item 80				
Age	21.952	1	.000	.004
Age x Behavioural Control	1.517	1	.218	
SES	12.193	1	.000	.081
SES x Behavioural Control	.336	1	.562	
Item 135				
Age	3.912	1	.048	.110
Age x Behavioural Control	7.093	1	.008	
SES	.100	1	.751	1.000
SES x Behavioural Control	.040	1	.842	

Table 6.4: *Emotional Control – Univariate tests for age, SES, and interaction-terms*

	χ^2	df	p-value	Adjusted p-value
Item 18				
Age	1.492	1	.221	.921
Age x Emotional Control	.056	1	.813	
SES	.456	1	.500	.754
SES x Emotional Control	2.155	1	.142	
Item 61				
Age	.046	1	.830	1.000
Age x Emotional Control	.021	1	.886	
SES	4.457	1	.035	.368
SES x Emotional Control	.082	1	.774	
Item 68				
Age	.003	1	.954	1.000
Age x Emotional Control	.196	1	.658	
SES	2.777	1	.096	.483
SES x Emotional Control	1.294	1	.255	
Item 82				
Age	2.963	1	.085	.658
Age x Emotional Control	.002	1	.965	
SES	.493	1	.483	.994
SES x Emotional Control	.162	1	.687	
Item 86				
Age	.072	1	.789	1.000
Age x Emotional Control	.026	1	.872	
SES	3.692	1	.055	.341
SES x Emotional Control	1.337	1	.247	

Table 6.5: *Problem Solving – Univariate tests for prior concussions and interaction-terms*

	χ^2	df	p-value	Adjusted p-value
Item 37				
Concussions	1.451	1	.228	.247
Concussions x Problem Solving	3.180	1	.075	
Item 56				
Concussions	6.287	1	.012	.206
Concussions x Problem Solving	.093	1	.760	
Item 77				
Concussions	.574	1	.449	.986
Concussions x Problem Solving	.346	1	.556	
Item 93				
Concussions	1.142	1	.285	.670
Concussions x Problem Solving	1.356	1	.244	
Item 111				
Concussions	4.046	1	.044	.493
Concussions x Problem Solving	.731	1	.393	
Item 127				
Concussions	.859	1	.354	.935
Concussions x Problem Solving	.530	1	.466	

Table 6.6: *Attentional Control – Univariate tests for prior concussions and interaction-terms*

	χ^2	df	p-value	Adjusted p-value
Item 5				
Concussions	.539	1	.463	.984
Concussions x Attentional Control	.678	1	.410	
Item 35				
Concussions	4.703	1	.030	.302
Concussions x Attentional Control	1.009	1	.315	
Item 65				
Concussions	.917	1	.338	.991
Concussions x Attentional Control	.058	1	.810	
Item 76				
Concussions	1.661	1	.197	.932
Concussions x Attentional Control	.175	1	.676	
Item 106				
Concussions	.321	1	.571	1.000
Concussions x Attentional Control	.214	1	.643	
Item 136				
Concussions	1.299	1	.254	.960
Concussions x Attentional Control	.137	1	.712	

Table 6.7: *Behavioural Control – Univariate tests for prior concussions and interaction-terms*

	χ^2	df	p-value	Adjusted p-value
Item 20				
Concussions	1.065	1	.302	.997
Concussions x Behavioural Control	.366	1	.545	
Item 33				
Concussions	.033	1	.856	.790
Concussions x Behavioural Control	3.768	1	.052	
Item 45				
Concussions	.049	1	.825	1.000
Concussions x Behavioural Control	.896	1	.344	
Item 70				
Concussions	.199	1	.656	1.000
Concussions x Behavioural Control	.332	1	.565	
Item 73				
Concussions	1.477	1	.244	.993
Concussions x Behavioural Control	.017	1	.896	
Item 75				
Concussions	.128	1	.720	1.000
Concussions x Behavioural Control	.069	1	.793	
Item 80				
Concussions	.080	1	.778	1.000
Concussions x Behavioural Control	1.000	1	.317	
Item 135				
Concussions	.273	1	.601	1.000
Concussions x Behavioural Control	.081	1	.776	

Table 6.8: *Emotional Control – Univariate tests for prior concussions and interaction-terms*

	χ^2	df	p-value	Adjusted p-value
Item 18				
Concussions	1.354	1	.013	.899
Concussions x Emotional Control	.023	1	.571	
Item 61				
Concussions	4.757	1	.000	.211
Concussions x Emotional Control	.108	1	.056	
Item 68				
Concussions	.191	1	.060	.997
Concussions x Emotional Control	.460	1	.008	
Item 82				
Concussions	.150	1	.000	.974
Concussions x Emotional Control	1.003	1	.000	
Item 86				
Concussions	1.607	1	.245	.544
Concussions x Emotional Control	.842	1	.081	

Table 7.1 *Problem Solving raw score to T/Z score conversions*

Raw Score	T Score	Z Score
6	30.72	-1.93
7	33.25	-1.67
8	35.78	-1.42
9	38.31	-1.17
10	40.84	-0.92
11	43.37	-0.66
12	45.90	-0.41
13	48.43	-0.16
14	50.96	0.10
15	53.50	0.35
16	56.03	0.60
17	58.56	0.86
18	61.09	1.11
19	63.62	1.36
20	66.15	1.61
21	68.68	1.87
22	71.21	2.12
23	73.74	2.37
24	76.27	2.63

Table 7.2 *Attentional Control raw score to T/Z score conversions*

Raw Score	T Score	Z Score
6	36.04	-1.40
7	38.51	-1.15
8	40.98	-0.90
9	43.45	-0.65
10	45.92	-0.41
11	48.39	-0.16
12	50.87	0.09
13	53.34	0.33
14	55.81	0.58
15	58.28	0.83
16	60.75	1.08
17	63.22	1.32
18	65.70	1.57
19	68.17	1.82
20	70.64	2.06
21	73.11	2.31
22	75.58	2.56
23	78.06	2.81
24	80.53	3.05

Table 5.3 *Behavioural Control raw score to T/Z score conversions*

Raw Score	T Score	Z Score
8	37.34	-1.27
9	40.08	-0.99
10	42.82	-0.72
11	45.57	-0.44
12	48.31	-0.17
13	51.06	0.11
14	53.80	0.38
15	56.54	0.65
16	59.29	0.93
17	62.03	1.20
18	64.77	1.48
19	67.52	1.75
20	70.26	2.03
21	73.00	2.30
22	75.75	2.57
23	78.49	2.85
24	81.24	3.12
25	83.98	3.40
26	86.72	3.67
27	89.47	3.95
28	92.21	4.22
29	94.95	4.50
30	97.70	4.77
31	100.44	5.04

Table 5.4 *Emotional Control raw score to T/Z score conversions*

Raw Score	T Score	Z Score
5	33.42	-1.66
6	36.84	-1.32
7	40.27	-0.97
8	43.70	-0.63
9	47.12	-0.29
10	50.55	0.06
11	53.98	0.40
12	57.40	0.74
13	60.83	1.08
14	64.26	1.43
15	67.68	1.77
16	71.11	2.11
17	74.54	2.45
18	77.96	2.80
19	81.39	3.14

Figure 1.1: *Model 1 for the executive behaviour screener*

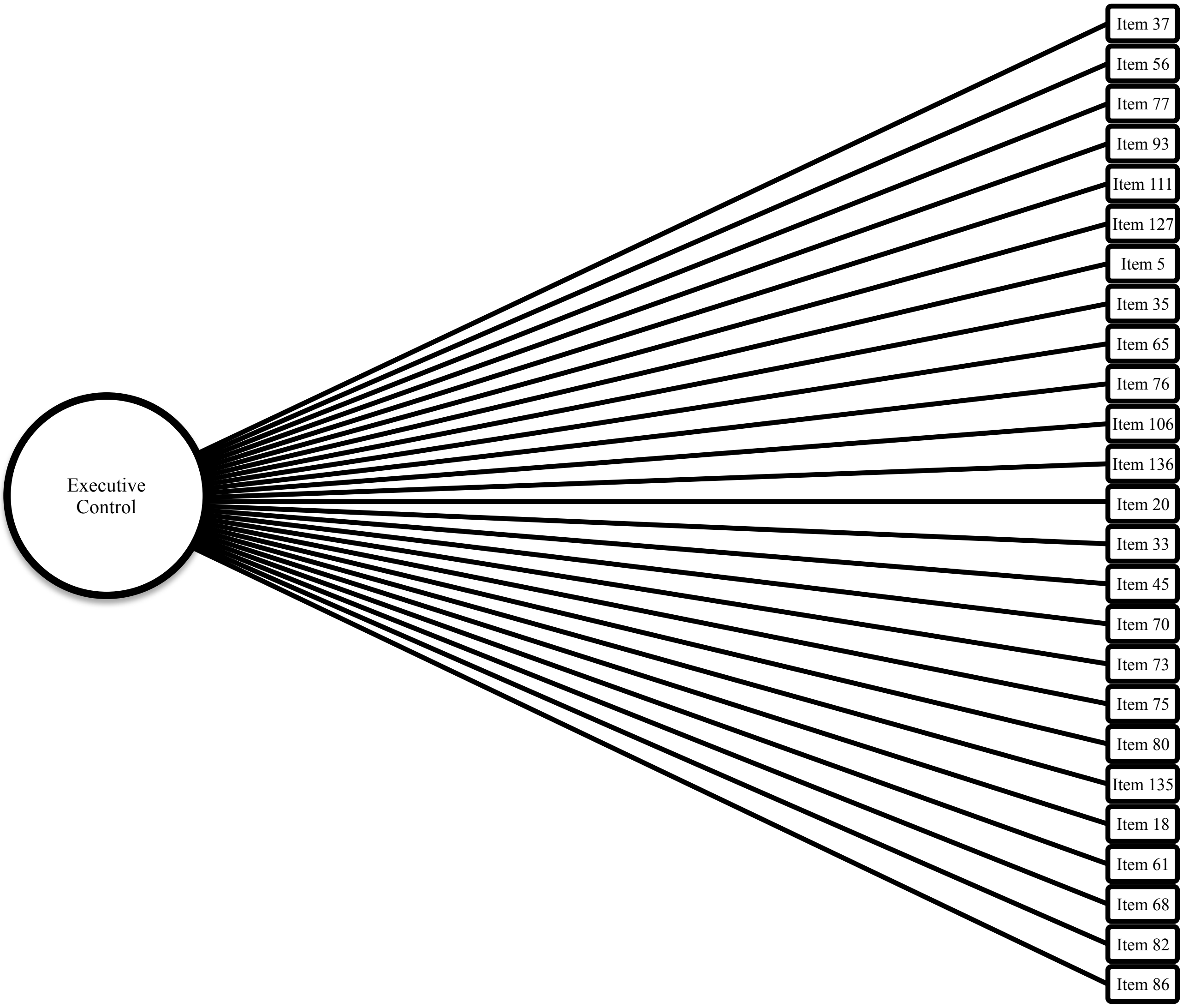


Figure 1.2: *Model 2 for the executive behaviour screener*

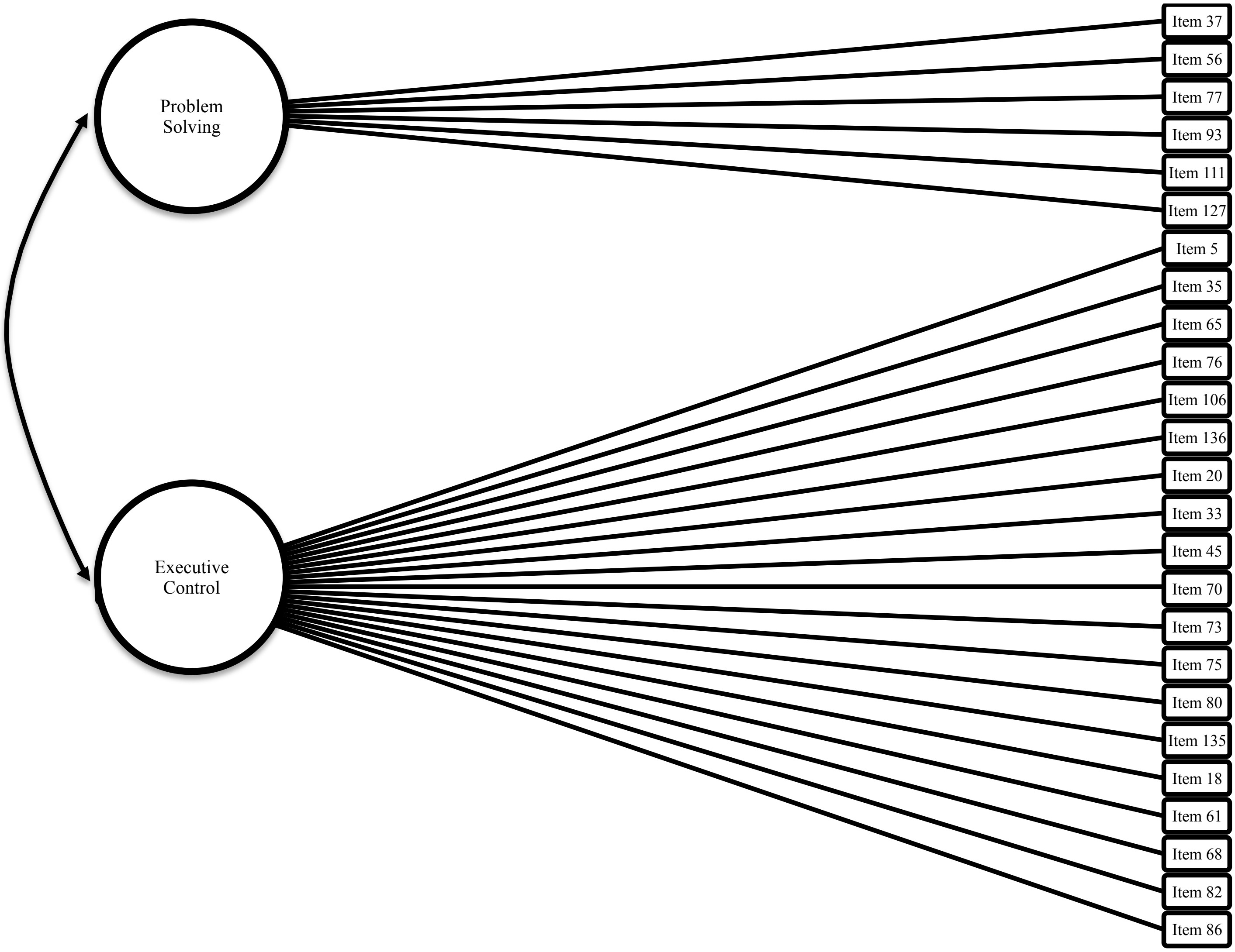


Figure 1.3: *Model 3 for the executive behaviour screener*

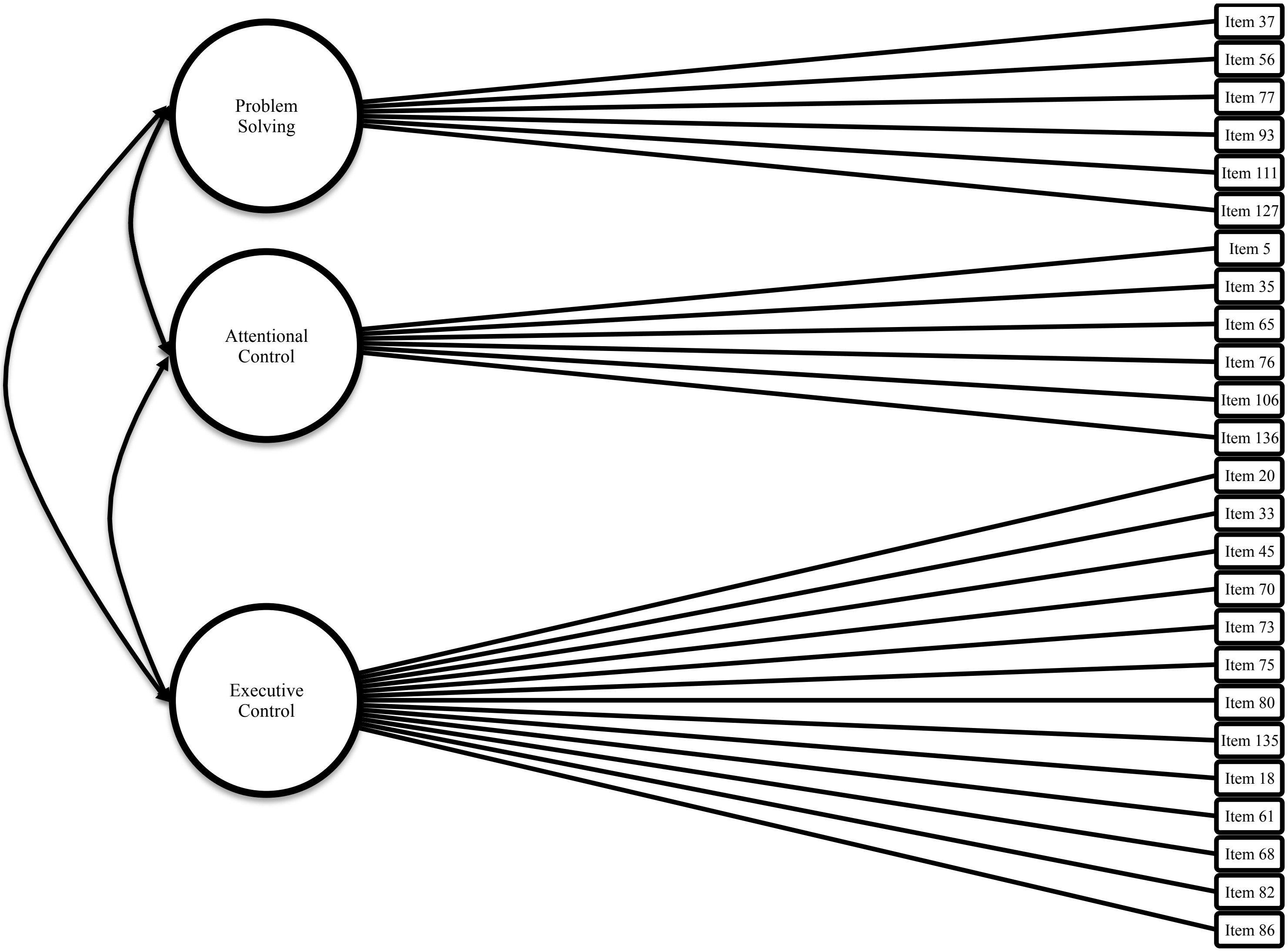


Figure 1.4: *Model 4 for the executive behaviour screener*

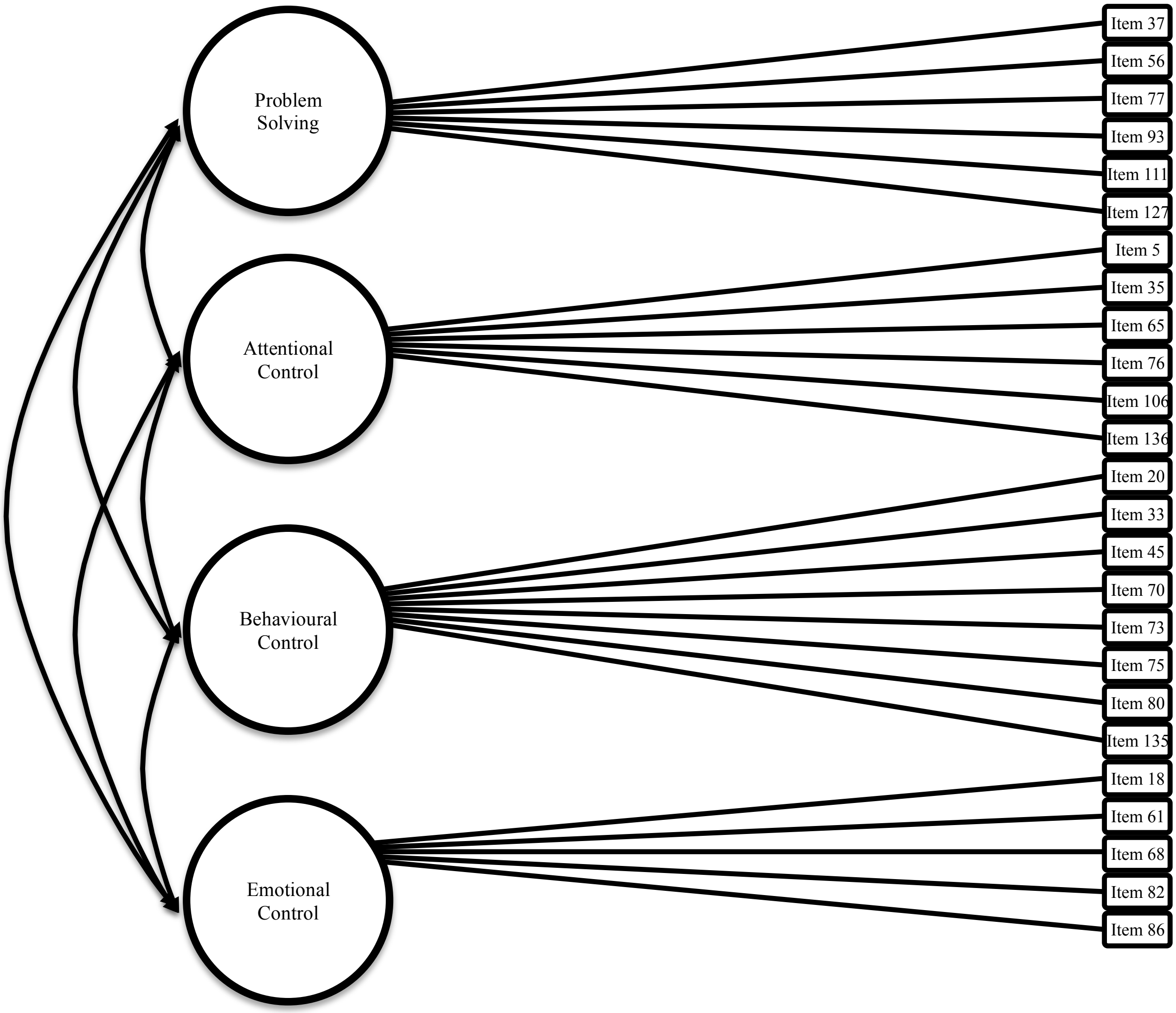


Figure 2.1: *Latent means between males and females*

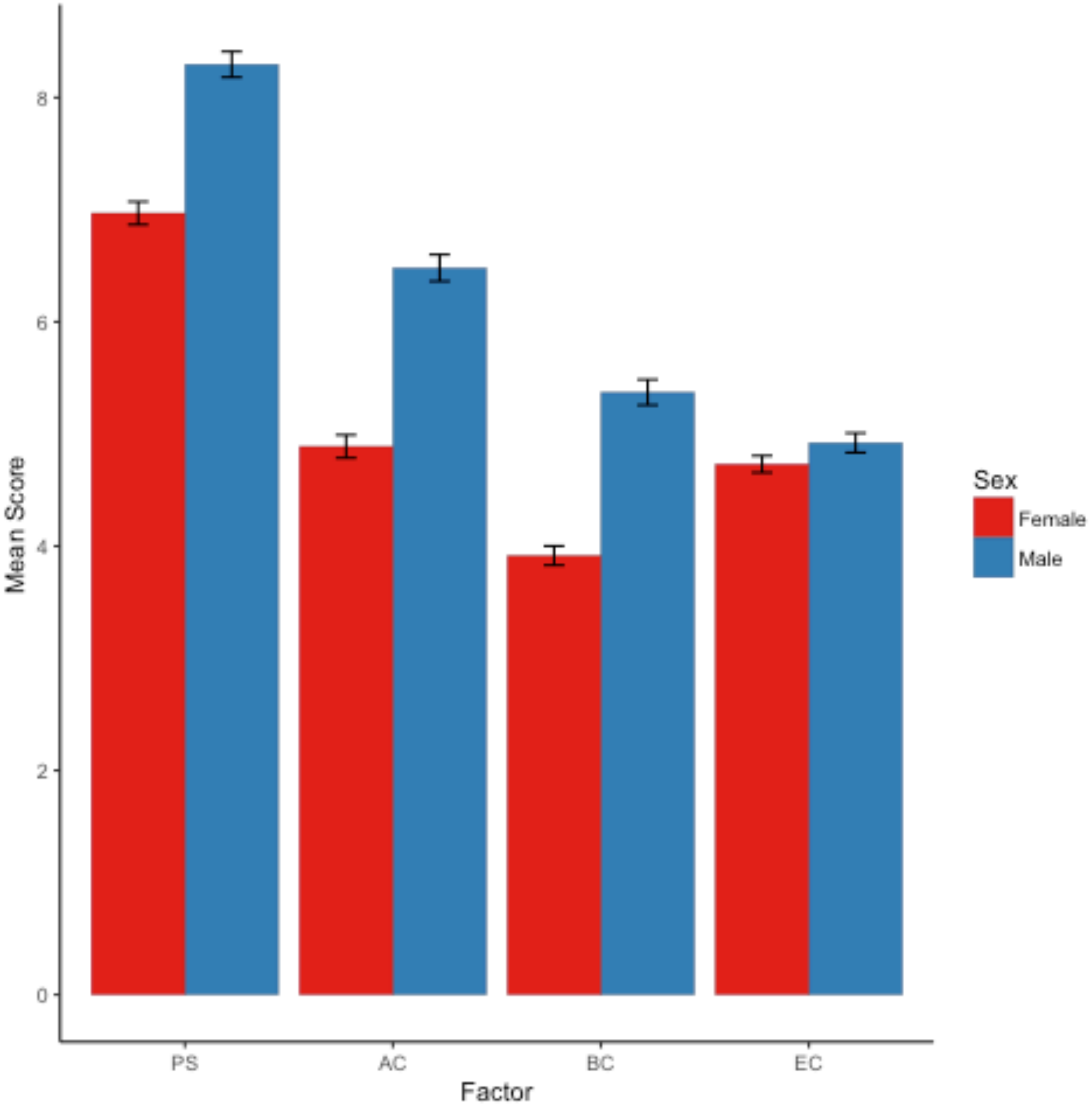


Figure 2.2: *Latent means of standardization and hockey samples*

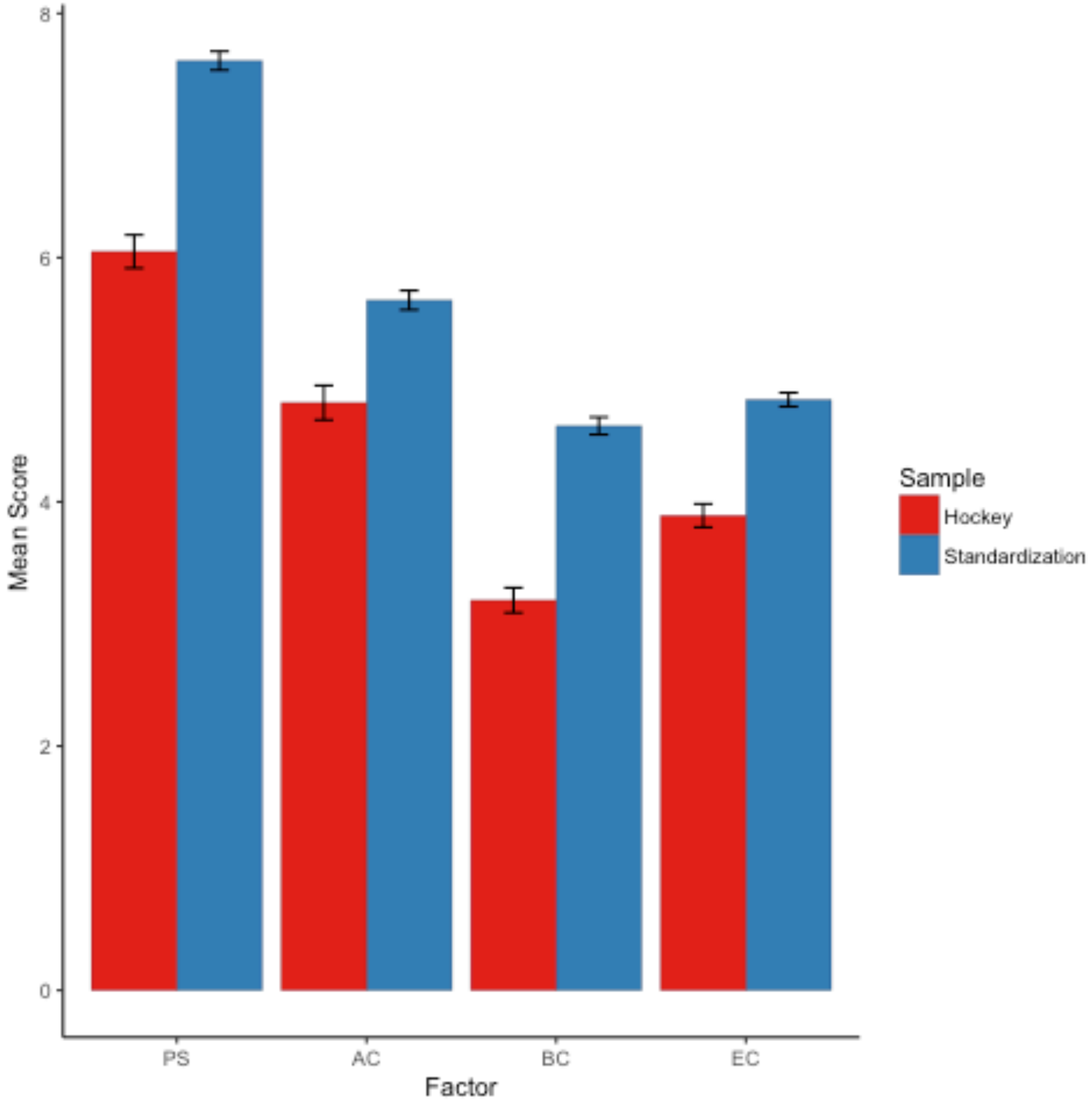


Figure 2.3: *Mean scale scores across ages*

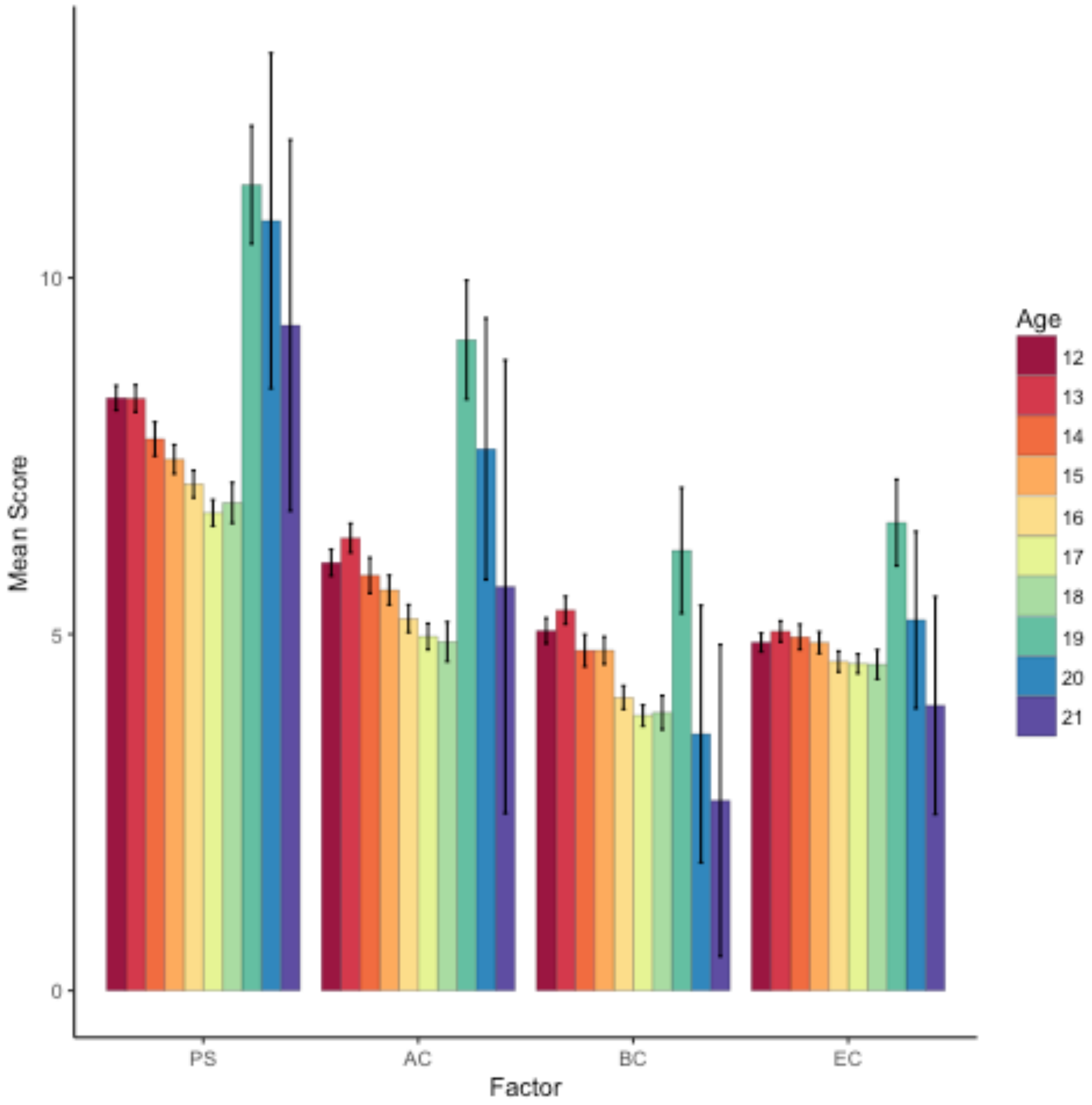


Figure 2.4: *Mean scale scores between parent education levels (SES)*

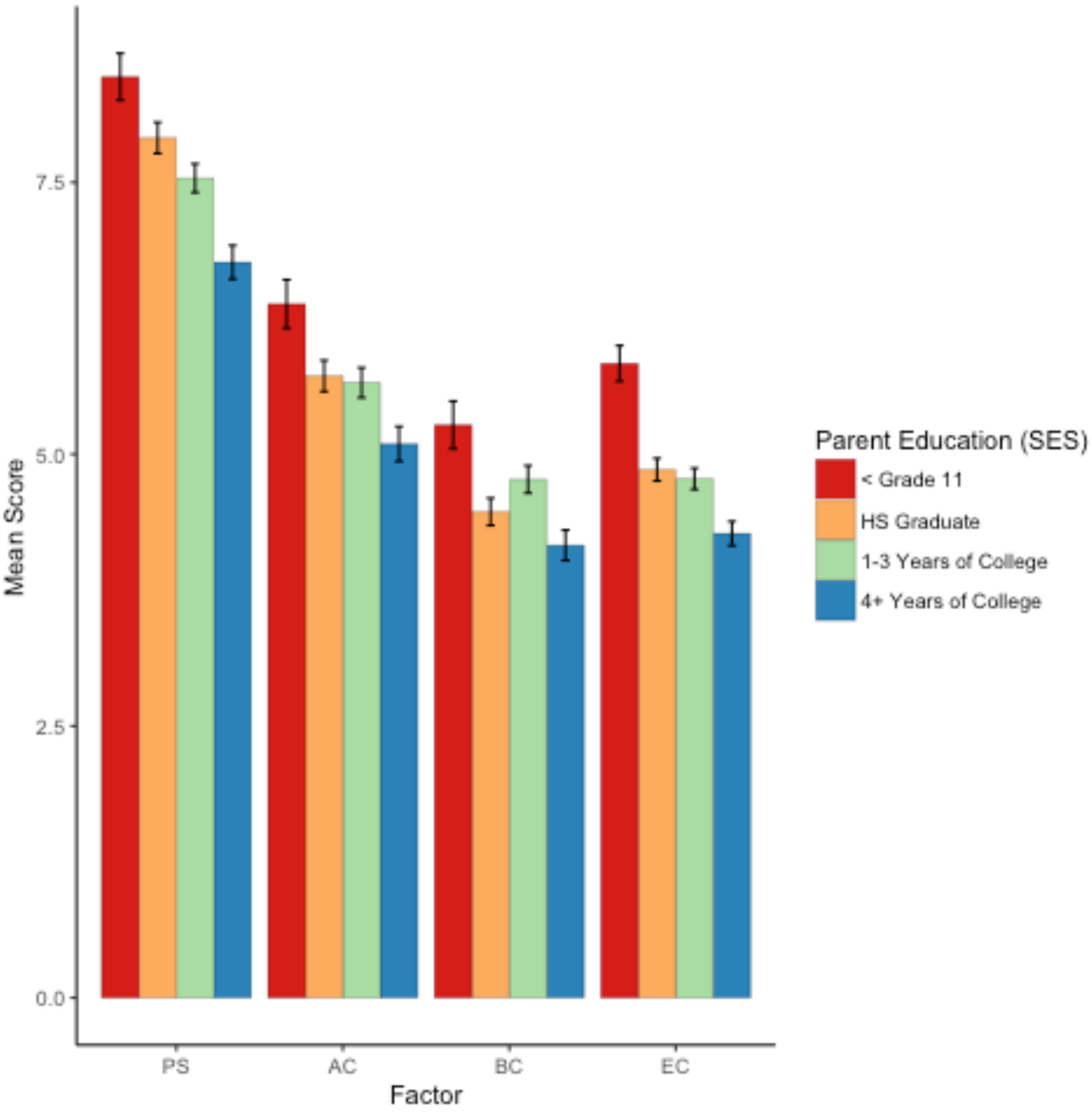


Figure 3: *Example of MIMIC model structure with Problem Solving and age*

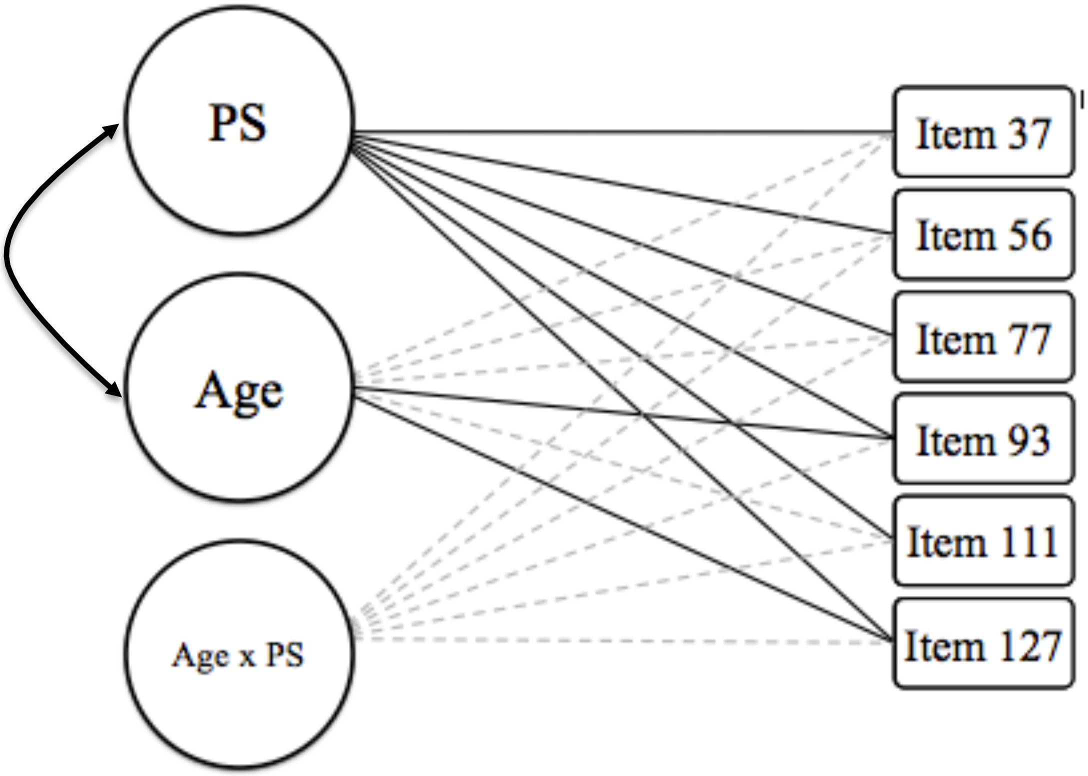
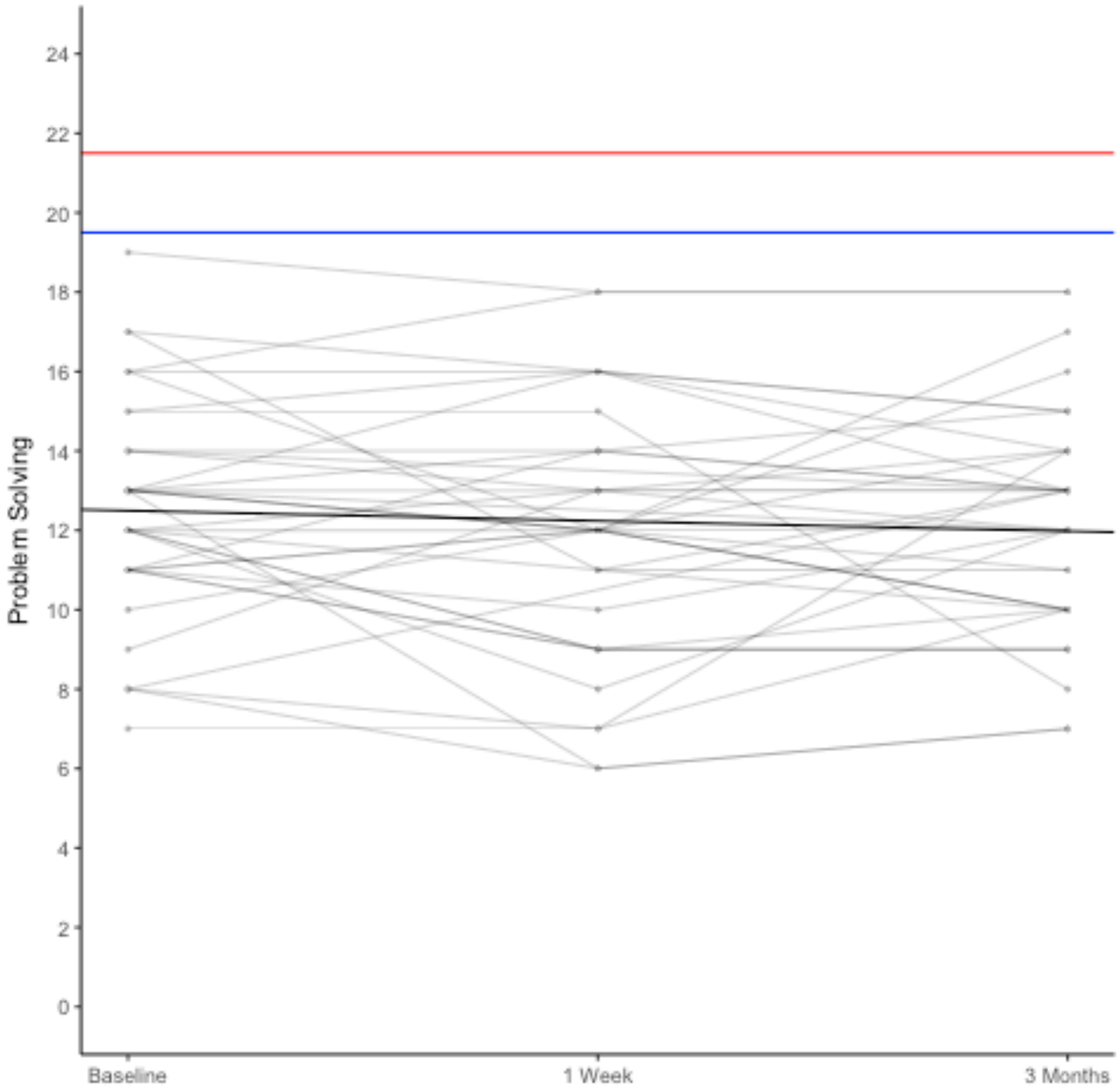
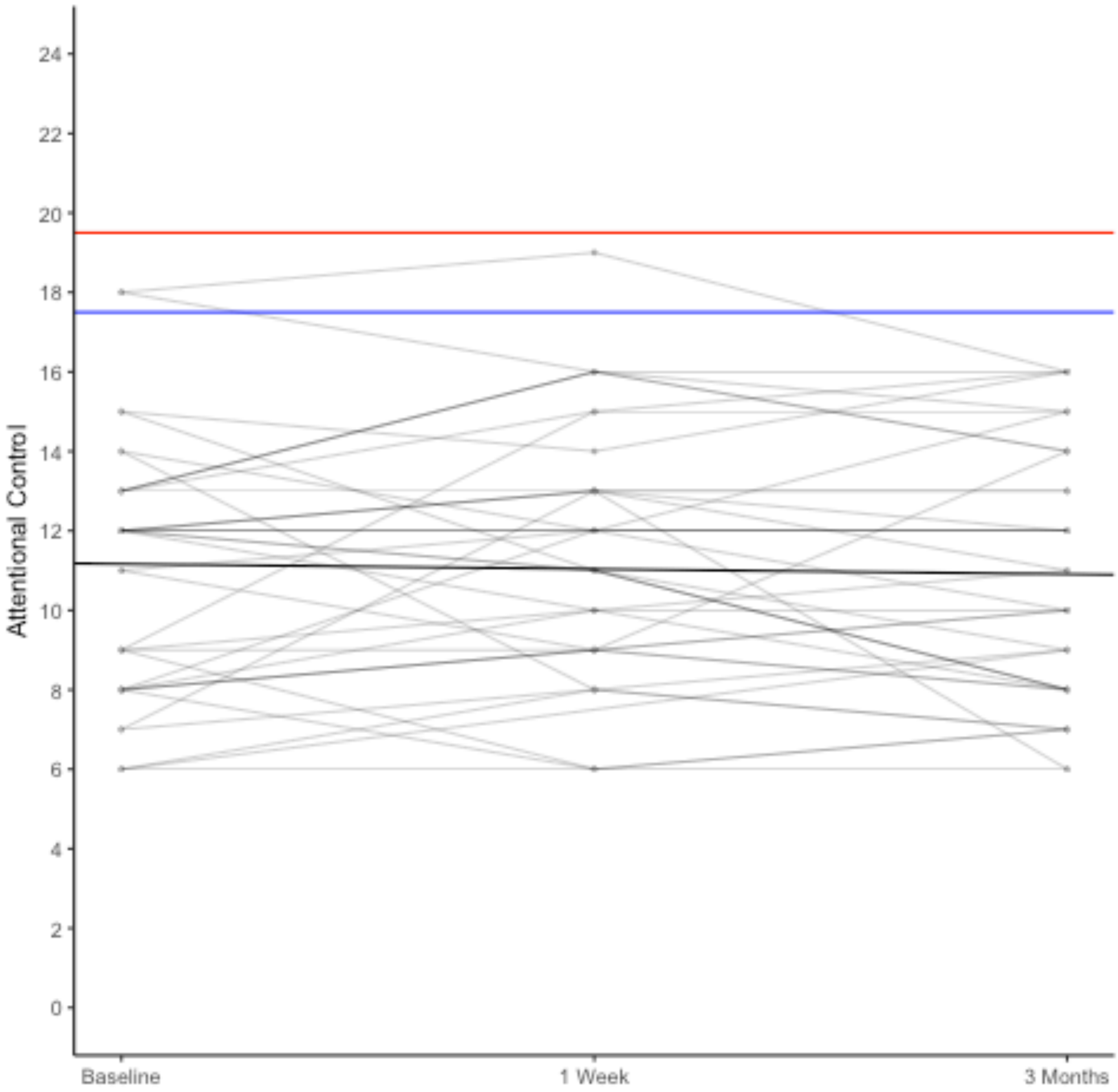


Figure 4.1: *Problem Solving factor over time for the subset of concussed hockey players*



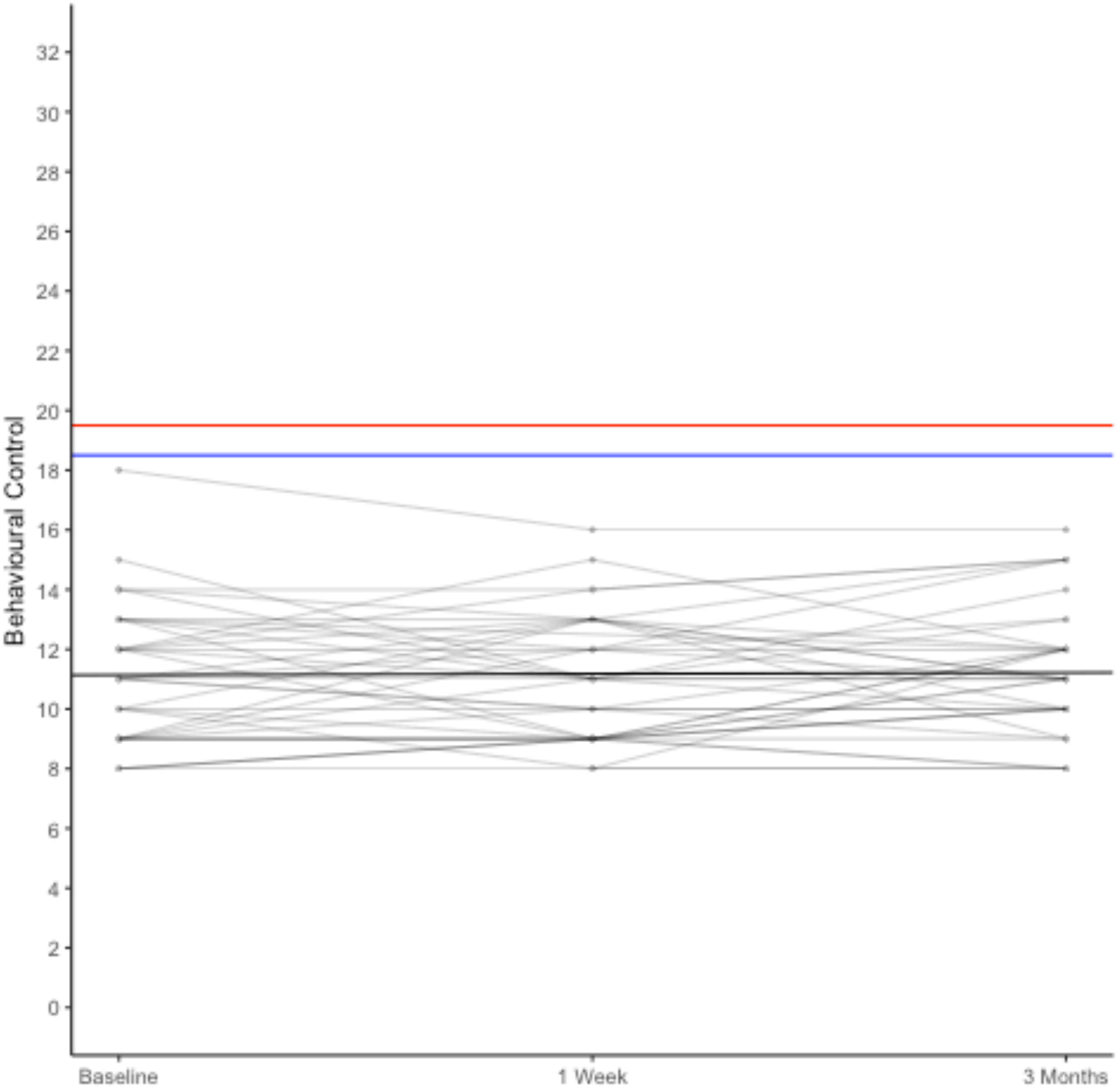
*The black line is the mean trajectory; blue and red lines are levels of clinical concern and risk, respectively

Figure 4.2: *Attentional Control factor over time for the subset of concussed hockey players*



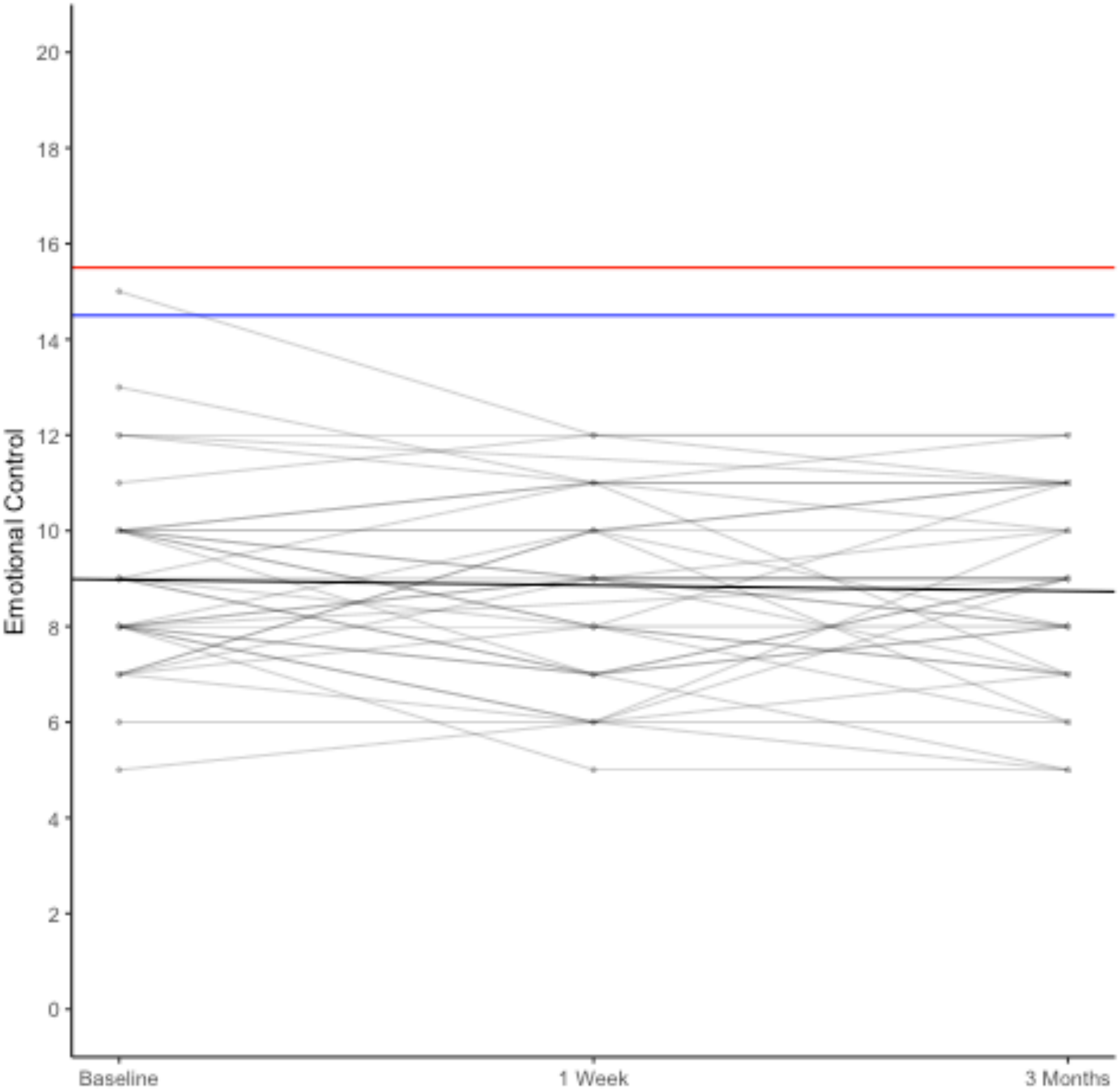
*The black line is the mean trajectory; blue and red lines are levels of clinical concern and risk, respectively

Figure 4.3: *Behavioural Control factor over time for the subset of concussed hockey players*



*The black line is the mean trajectory; blue and red lines are levels of clinical concern and risk, respectively

Figure 4.4: *Emotional Control factor over time for the subset of concussed hockey players*



*The black line is the mean trajectory; blue and red lines are levels of clinical concern and risk, respectively

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