Stability and Predictors of Change in Executive Functions from the Age of 6 to 8

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Abstract

Executive functions have been identified as major predictors of a range of developmental outcomes in children including social adjustment, mental health and academic achievement. However, there are considerable gaps in our knowledge regarding what affects the development of executive functions. By examining a large community sample of 6 year olds (N=687) and their parents with follow-up at age 8, this study aimed at filling in some of these gaps by analyzing a range of likely predictors of the development of executive functions. Measures of three components of executive functions; working memory, inhibition and set shifting, were obtained. Predictors included were emotion regulation, socioeconomic status, attachment, experience of major stressful life events, and parental emotional availability. Executive functioning evidenced little stability from age 6 to 8. Growth factor modeling revealed that experiencing of major stressful life events predicted a diminished increase in executive function from age 6 to 8. Findings are discussed in relation to theory and empirical data on the development of executive functions.

Stability and Predictors of Change in Executive Functions from the Age of 6 to 8

Executive functions are emerging as key factors in children's successful adjustment. There are positive associations between executive function and academic achievement (C. Blair, 2002), good mental health (Berlin, Bohlin, & Rydell, 2003) and social adjustment (Razza & Blair, 2009). Enhancing executive functioning may therefore be a promising component in preventive and treatment efforts. Uncovering factors that has an effect on the development of executive functions will provide useful information to clinicians to give better treatment and reveal which children are at risk.

Executive functions develop through interactions with other people (Bernier, Carlson, & Whipple, 2010), and there are emerging evidence that different factors in the environment effects the development of executive functions in children (Müller, Baker, & Yeung, 2013). Still there are considerable gaps in the literature. A limited number of studies have investigated what influences the development of executive functions over time and it is uncertain if one or more factors have significant influence over and above other factors. Few studies have measured executive functions at several points of time, and thus little is known about the stability of executive functions in childhood. Further, only a limited number of studies has examined the development of executive functions in middle and late childhood – a period of allegedly rapid development in these functions (P. Anderson, 2002). The present study aims to fill some of these gaps in knowledge by exploring predictors of change in executive functions, as well as the stability of executive functions, in a large and representative sample of children.

Executive functions

Executive function can be defined as the conscious control of thought and action that is needed for future-oriented and purposeful behavior (Welsh, Pennington, & Groisser, 1991). Executive function is considered to be a cognitive form of self-regulation (Royall et al., 2002) and consists of a large number of discrete interrelated cognitive processes that include working memory, attention control, attention shifting, cognitive flexibility, self-monitoring, and inhibitory control of prepotent responses (Wise, 1999). In a seminal study, Miyake et al. (2000) conducted a confirmatory factor analysis that indicated three target executive functions among adults; one involving updating and monitoring of information, one involving mental set shifting and one involving inhibition. Today there is general agreement that executive functions in adults can be divided into three core components equivalent to those found by Miyake et al. (2000); inhibition, working memory and set shifting (Diamond, 2013).

Inhibition is defined as the ability to inhibit a prepotent response, and includes selective attention as well as behavioral and cognitive inhibition. Working Memory involves holding information in mind and mentally operating on it. Set shifting is also referred to as cognitive flexibility or mental flexibility and involves the ability to alter ones approach to a problem and adjust to new demands or rules in a flexible way (Diamond, 2013).

When it comes to children, the categorization of executive functions is less clear. There is evidence that executive function is a unitary factor in preschoolers (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011), but others have found that it consists of two factors; inhibition and working memory (M. R. Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012). In school-age children there appear to be a division of the executive functions into three components (Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003; Rose, Feldman, & Jankowski, 2011) resembling the devising of executive function in adults. Wiebe et al. (2011) argues that executive functions may be a unitary factor in early childhood, and that it develops into three discreet components as children mature.

Executive functions play an important role in a child's development of intellectual abilities (Brydges, Reid, Fox, & Anderson, 2012), academic abilities (Neuenschwander, Roethlisberger, Cimeli, & Roebers, 2012), personality (Murdock, Oddi, & Bridgett, 2013), social skills (Razza & Blair, 2009) and communication (McEvoy, Rogers, & Pennington, 1993). Deficits in executive functions have been related to a vast range of unfortunate outcomes in children, such as aggression, inattention, behavior problems and peer problems (Bridgett, Valentino, & Hayden, 2012; Riggs, Blair, & Greenberg, 2004). Deficits in executive functions are further related to social maladjustment (Riggs et al., 2004) and different psychiatric diagnoses like ADHD (Pineda, Puerta, Aguirre, García-Barrera, & Kamphaus, 2007; Sonuga-Barke, Dalen, Daley, & Remington, 2002) and autism (Pennington & Ozonoff, 1996), whereas higher levels of executive functions have been found to relate to positive adjustment outcomes (C. Blair & Peters, 2003; Carlson, Mandell, & Williams, 2004). Hence, understanding what affects the development of executive functions in children will be of importance to treatment and prevention of mental disorder. In this study we aim to provide such understanding.

There are few studies regarding the stability of executive functions in children, and results are mixed. Polderman et al. (2007) reported a relatively low correlation in working memory from the age of 5 to 12, and non-significant stability of working memory has been found in preschoolers (Hammond, Mueller, Carpendale, Bibok, & Liebermann-Finestone, 2012; Hughes, Roman, Hart, & Ensor, 2013). However, Cuevas, Hubble, and Bell (2012) showed that kindergarten working memory significantly predicted executive functions measured by a questionnaire-based measure , two years later, and Carlson et al. (2004) reported relative stability in inhibition between the age of 2 to 3. Several of the longitudinal studies on executive function in children apply different measures of executive function at baseline and follow-up (e.g. Carlson et al., 2004; Cuevas et al., 2012), making examination of stability difficult. Further, of the cited studies, only Polderman et al. (2007) included children older than 5 years, and stability of inhibition and set shifting was not investigated. Studies of adolescents has shown substantial stability in executive functions (Boelema et al., 2013), suggesting that stability might increase with age, stressing the need for investigation of stability in executive functions also in school aged children. In the present study, the stability of working memory, inhibition and set shifting will be investigated to clarify to what extent executive functions are stable between 6 to 8 years.

Although there are great overall improvement in executive functions during childhood (Best & Miller, 2010), the rate of this improvement varies considerably between children, hence sizable variability in relative stability has been reported (Biederman et al., 2008). Given the importance of executive functions a pertinent question arises: "What are the reasons for these variabilities in development between children?" In light of Gottlieb's theory of probabilistic epigenesis (Gottlieb, 2007), C. Blair and Raver (2012) pointed out that individuals would benefit from a plasticity of the executive functions because different environments calls for different levels of executive control. This assumption is in line with the fact that executive function has a protracted development throughout childhood (P. Anderson, 2002) and thus are amenable to environmental influences during all stages of childhood. There is also a growing body of empirical evidence suggesting that executive function is malleable by environmental factors (Müller et al., 2013) and environmental influences are shown to interact with genetic factors in affecting the development of executive functions (Hughes, 2011; Kochanska, Philibert, & Barry, 2009). Among environmental factors that are found to influence the development of executive functions in children are experience of institutional care (McDermott, Westerlund, Zeanah, Nelson, & Fox, 2012), the caregiving environment (Bernier, Carlson, Deschenes, & Matte-Gagne, 2012), maternal positive affect (Kraybill & Bell, 2013), and maternal mental health (Hughes et al., 2013). In summary, a range of individual and environmental factors can explain the variability in development of executive functions between children. I will now review the environmental factors most extensively investigated.

The influence of the home environment on executive functions

It has been proposed that children develop their regulating abilities by first being regulated by adults and gradually becoming more self-regulated (Berger, 2011). Hence, the caregiving environment is of great importance when considering factors affecting the development of executive functions. Indeed, aspects of the caregiving environment are found to have an important effect on the development of executive functions (Hewage, Bohlin, Wijewardena, & Lindmark, 2011; Rhoades, Greenberg, Lanza, & Blair, 2011). It has been shown that children growing up in institutional care, where interaction with adults are rarer, have poorer executive functions compared to controls (McDermott et al., 2012). Positive parent practices such as positive reinforcement and comfort, has been found to correlate with aspects of executive functioning in children exposed to domestic violence (Samuelson, Krueger, & Wilson, 2012). Similar findings have also appeared when studying typically developing children (Bernier et al., 2010) suggesting that parental practice has an impact on children's executive functions. It has repeatedly been found that scaffolding – the process where adults support children in problem-solving activities, with supporting behaviors such as modeling, discussion, maintenance of the child's attention and encouragement (Stone, 1998) – seem to promote the development of executive functions (Bibok, Carpendale, & Muller, 2009; Conway & Stifter, 2012; Hammond et al., 2012; Hughes & Ensor, 2009). In sum, there is evidence that parental behaviors characterized by sensitivity, support, reinforcement and comfort are positively related to child executive function. However, in all the cited research, only Hammond et al. (2012) measures baseline levels of executive function, and are thus the only study that could control for initial levels of executive functions. The study of Hammond and colleges, included children aged 2 to 4. Hence, no study prior to our have investigated this relationship in children older than 4. Parental influence is likely to decrease as children grow older (Harris, 1995; Steinberg & Morris, 2001), and therefore it is crucial to investigate whether parental behaviors such as sensitivity and support, also effects change in executive function in children older than 4 years. This study aims at exploring this possibility.

There is also emerging evidence that attachment influences the development of executive functions. Attachment is a specific part of the relation between the child and the caregiver where the caregiver gives the child security and protection but also supports it in explore the surrounding world (Benoit, 2004). A secure form of attachment is characterized by a balance between protection and encouragement of exploration (Weinfield, Sroufe, Egeland, & Carlson, 2008). It is possible that children who are securely attached are less preoccupied about safety than unsecure children, and thus can explore the world with more mental resources available to develop executive functions. Bernier et al. (2012) found that attachment at 2 years predicted working memory and set shifting at 3 years. Further, parenting styles associated with secure attachment, such as encouraging exploration, has been found to be related to better self-regulating abilities in children (Piotrowski, Lapierre, & Linebarger, 2013).

As aspects of the home and care-giving environment is shown to have a positive effect on executive functions in children, some aspects of the home environment can have a negative effect. Low socioeconomic status seems to have such a negative effect. Socioeconomic status is a concept involving multiple factors. The most frequently used indices of socioeconomic status is parental education, occupation and income (Ensminger & Fothergill, 2003). Low socioeconomic status is found to be related to lower levels of executive function in children (Catale, Willems, Lejeune, & Meulemans, 2012; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005; Sarsour et al., 2011). However, it has been found that the effect of socioeconomic status on executive function is accounted for by parenting behaviors such as scaffolding (Dilworth-Bart, Poehlmann, Hilgendorf, Miller, & Lambert, 2010). Rhoades et al. (2011) found that the effect of socioeconomic status on executive functions was mediated by the quality of parent-child interaction. As noted, parenting behaviors seem to be important for the development of executive functions, and as parenting practices may vary across socioeconomic status, this might be the reason socioeconomic status is found to affect executive functions. Another possible link between socioeconomic status and executive function is that low socioeconomic status is related to a higher level of stress and that this level of stress affects the executive functions (Evans & Kim, 2013; Evans & Schamberg, 2009). Measures of cortisol (a stress hormone), have been reported to be significantly related to executive function in children (Berry, Blair, Willoughby, & Granger, 2012; C. Blair, Granger, & Razza, 2005; Clancy Blair et al., 2011). Findings from animal models suggest that brain regions related to executive functions are damaged as a consequence of stress (Cerqueira, Mailliet, Almeida, Jay, & Sousa, 2007; Murmu et al., 2006). However, to our knowledge, no one has investigated the relationship between stress and executive functions in children over time, controlling for initial levels of executive functioning. Thus, the causality of this relationship is not certain. It might be that lower levels of executive functions make children more prone to seek potentially stressful situations. For example, a child with low levels of inhibition will possibly take more risks and, as a consequence, take part in dangerous situations which can be stressful.

The influence of emotion regulation on executive functions

Emotion regulation can be defined as how individuals alter their emotions and how the emotions are experienced and expressed (Gross, 1998). As both emotion regulation and executive functions are regulating abilities, one would expect the two constructs to be related. It has been proposed that successful emotion regulation relies on executive functions (Zelazo & Cunningham, 2007). However, the results are mixed. It has been found that the ability to regulate emotions and executive functions are associated both in preschoolers (Carlson & Wang, 2007) and in school aged children (Simonds, Kieras, Rueda, & Rothbart, 2007). However, Liebermann, Giesbrecht, and Mueller (2007) found no significant association between executive function and emotion regulation in preschoolers. Again, the cited research is cross-sectional. Thus, it is at present unknown whether these associations, if they indeed are present, can be attributed to any causality. A temporal ordering of emotion regulation and executive functions would provide preliminary evidence about causality. This is the line of investigation pursued in the present research.

Summary and objective of the current study

Important advances in understanding the development of executive functions have been made in recent years. It has been shown that parent practices (Conway & Stifter, 2012), attachment (Bernier et al., 2012), emotion regulation (Ursache, Blair, Stifter, & Voegtline, 2013), stress (Berry et al., 2012), and socioeconomic status (Noble et al., 2007) are related to executive functions in children. Nevertheless, there are considerable gaps in our knowledge on this topic. Firstly, there is a lack of longitudinal studies in this line of research. The majority of the studies are cross-sectional (e.g. Catale et al., 2012; McDermott et al., 2012; Noble et al., 2007; Noble et al., 2005; Samuelson et al., 2012), and most of the longitudinal studies that exist have only measured executive functions at one point of time (e.g. C. Blair et al., 2005; Clancy Blair et al., 2011; Dilworth-Bart et al., 2010; Evans & Schamberg, 2009). Unmeasured executive functioning at the time when predictors are examined could explain the obtained results, the research above has not put the predictive relationship to a strong test. To my knowledge only three studies have investigated predictors of executive functions controlling for baseline executive function (Bernier et al., 2012; Hammond et al., 2012; Hughes et al., 2013). None of these studies included children older than 4 years. Predictors investigated in these studies were maternal mental health (Hughes et al., 2013), scaffolding (Hammond et al., 2012) and attachment (Bernier et al., 2012). Hence, no study has investigated the effect of stress, socioeconomic status, or emotion regulation on *growth* in executive function in children.

Secondly, related to the fact that few studies re-test levels of executive function, the stability of executive functions in childhood is not established. Some studies indicate relative stability (Carlson et al., 2004) whereas others indicate little stability (Hammond et al., 2012). It is unclear whether the stability is different for different forms of executive functions (inhibition, shifting and working memory) – working memory has been most extensively studied (Hammond et al., 2012; Hughes et al., 2013; Polderman et al., 2007), - few studies have investigated the stability of inhibition and set shifting. Further, little is known about stability in children older than 5 years.

Thirdly, different aspects of executive function are known to improve at different ages (Hughes, 2011). Taken together with evidence that executive functions develops throughout childhood (P. Anderson, 2002) this calls for a thorough investigation of what factors contribute to the development of which executive functions at different ages. To date the majority of the research on the development of executive functions has investigated children under the age of 5 (Best & Miller, 2010).

The current study addresses these shortcomings by exploring change in executive functions in a large and representative sample of children from the age of 6 to 8. The aim of the current study is to investigate the stability of executive functions in children, and explore whether socioeconomic status, stress, emotion regulation, parental emotional availability, and attachment predict change in executive functions from age 6 to 8. Based on earlier research it was hypothesize that 1) the stability in executive functions from age 6 to 8 will be low or non-significant, and that 2) parental emotional availability, socioeconomic status, stress, attachment and emotion regulation will predict change in executive function from 6 to 8 years.

Method

The study reported here is part of a larger study in which longitudinal relations between possible risk factors and children's psychosocial development is explored (see Wichstrom, Belsky, & Berg-Nielsen, 2013; Wichstrøm et al., 2012)

Participants and procedure

All children born in 2003 or 2004 in Trondheim, Norway, and their parents were invited to participate in a longitudinal study on children's psychosocial development and mental health. As shown in Figure 1, 82.1% (2,475) of the eligible families consented to participate, at initial testing when the children were 4 years of age. Because measures of executive function were included only from the first retesting, when the children was 6 years (T2), the present study only use data from T2 and the next follow-up at age 8 (T3).

Descriptive information on the sample at the first retest (when the children were approximately 6 years) is presented in Table 1. At the first data collection (6.7 years, SD=.17), 760 children participated. At the follow-up, 2 years later (8.8 years, SD=.24) 687 children participated. To investigate whether factors included in this study predicted drop-out logistic regression was applied. First, participation or not was regressed on each of the study variables and the results showed that stress (O.R. = .80, p = .002) parental emotional availability (O.R. = 1.02, p =.022) and inhibition (O.R. = 1.93, p = .048) at age 6 significantly predicted participation at age 8. When these three variables were included in a multivariat logistic regression only stress (O.R. = .75, p = .001) and parental emotional availability (O.R. = 1.02, p = .025) predicted drop out at age 8 (R^2= .03 (Cox & Snell), .05 (Nagelkerke)). All testing and observation of the children took place at the Department of Psychology, at the Norwegian university of Science and Technology (NTNU), and was performed by skilled personnel (n=7) who had at least a bachelor’s degree in a relevant field and extensive prior experience in working with children and families. The parents gave their written consent to participate. Procedures were approved by the Regional Committee for Medical and Health Research Ethics.

Measures

Outcomes

Inhibition. The “NEPSY: A Developmental Neuropsychological Assessment (NEPSY) Statue-test” (Korkman, Kirk, & Kemp, 1998) was used as a test of inhibition. In the NEPSY Statue-test the child is required to stand still for 75 seconds in a position like a “statue” (eyes closed, no body movements or vocalizations) holding a flag. At pre-set intervals distracters are introduced (e.g. the examiner drops a pen). At every interval the child is awarded 1 points if he/she mange to stay still, and no points if he/she makes one or more inappropriate response (body movement or vocalization). Thus, a higher score indicates better inhibition abilities. The NEPSY has adequate to high reliability (including internal consistency and test-retest reliability), validity, and interscorer agreement (Brooks, Sherman, & Strauss, 2009). Several other studies have used the NEPSY Statue-test as a measure of inhibition (Espy, Sheffield, Wiebe, Clark, & Moehr, 2011; Youngwirth, Harvey, Gates, Hashim, & Friedman-Weieneth, 2007).

Working Memory. To measure working memory we used the task “Digit Span” from Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003). The subtest Digit Span is a measure from the Working Memory Index, and several other studies involving children has used this task as a measure of working memory (M. Miller, Nevado-Montenegro, &

Hinshaw, 2012; Qian, Shuai, Chan, Qian, & Wang, 2013). The test first requires the child to orally repeat presented digit strings (number recall forward) and then the child is asked to name the digits in the reverse order of how they are presented (number recall backward) (Wechsler, 2003). Only the latter requires working memory ability as the child has to both hold information in mind (which numbers that are presented) and mentally operate on that information (reverse the digit string). Thus, we use the sum score of number recall backwards as a measure of working memory. A high score indicate good performance.

Set shifting. Intra-Extra Dimensional Set Shifting (IED), a subtest of the Cambridge Neuropsychological Test Battery (CANTAB) was used to asses set shifting. The IED assesses the ability to maintain attention to different stimuli within a relevant dimension (intradimensional shift, IDS) and then shift attention to a previously irrelevant dimension (extra-dimensional shift, EDS). The test is presented on a computer. The child must learn a specific rule to understand which of two stimuli presented is correct, based on feedback from the computer. Two different types of objects can appear; color filled shapes and white lines. The child first has to focus on the color filled shapes (IDS), then the white lines (EDS). After 6 correct answers the rule change, and the child is required to adapt to this. If the child does not learn the rule within 50 trials, the test terminates (Cambridge Cognition, 2013). A range of studies has used CANTAB to asses executive functions in children (O'Brien, Dowell, Mostofsky, Denckla, & Mahone, 2010; Rasmussen, Soleimani, & Pei, 2011) and it has been found to be a valid measure in child populations (Henry & Bettenay, 2010). High internal consistency has been reported (Luciana, 2003).

It has been argued that measures of accuracy is the best measure of shifting (van der Ven, Kroesbergen, Boom, & Leseman, 2013). In the current study we therefore used the outcome "total errors adjusted" which is a measure of how many mistakes the child makes, adjusted for how many stages she has completed, and "EDS errors" which is a measure of errors made in the extra-dimensional stage of the task. Both these measures reflect error and hence, accuracy. A high score indicates low set shifting ability – low scores indicates few errors.

Predictors

Emotion Regulation. Emotion Regulation Checklist (ERC; Shields & Cicchetti, 1997) was used to asses children's emotion regulation skills. The ERC is a 24 items self-report measure where parents' report their child's typical methods for managing emotional experiences. The test has two subscales (1) Lability/Negativity and (2) Emotion Regulation. The first assesses inflexibility, liability and dysregulated negative affect (e.g. "Exhibits wide mood swings”). The second assesses appropriate emotional expression, empathy and emotional self awareness (e.g. “Can modulate excitement in emotionally arousing situations”). In the current study we used the subscale Emotion Regulation as this most clearly reflects the child’s ability to regulate emotions. Reliability coefficients have been found to be high for the overall scale (.89) and for the subscales Emotion Regulation (.83), and validity has been established through positive correlations with how observers rated children’s abilities to regulate and their proportion of expressed positive and negative affect (Shields & Cicchetti, 1997).

Stress. The Preschool Age Psychiatric Assessment (PAPA; Egger, Ascher, & Angold, 2003), was used to measure children’s experience of stress. The PAPA is a developmentally appropriate interview-based instrument that includes all relevant DSM-IV criteria. It uses a structured protocol involving both required and optional follow-up questions. Questions was answered by a primary caregiver of the child (primarily the mother, see Table 1). The administration of the interview was conducted by trained research assistants. In this study we used information obtained on children’s experiences of major stressful life events (e.g. major accidents, death of parent, abuse). The PAPA has established test-retest reliability, and is widely used (Egger et al., 2006).

Attachment. To measure attachment we used the Manchester Child Attachment Story Task (MCAST; Green, Stanley, Smith, & Goldwyn, 2000). The MCAST is a doll-play vignette completion method where the child first is presented with vignettes designed to elicit attachment representations and then is instructed to complete the stories, that is to play them out using a dollhouse and two dolls, one representing the child and one representing the parent. First, to determine the testability of the child, the child is presented with a vignette not related to attachment (eating breakfast), then there are four vignettes with stories designed to elicit attachment behavior; (1) in the night the child has a nightmare; (2) the child hurts his/her knee; (3) the child has a tummy ache; and (4) the child is lost at a big mall. The task is taped, and coded by certified assistants to identify and classify internal representations of attachment relationship in the children. We measured attachment on a dimensional basis, rather than categorical, and rated how securely attached the child was. The primary categorization (A, B, C, D) of each vignette was coded as 1 (present) or 0 (absent) and a secondary classification was coded as 0.5 (present) or 0 (absent). A B-score was computed by averaging primary and secondary scores (range 0-1) across the four vignettes. Hence, a child who attained a primary classification of B on three vignettes and a secondary classification of B on one vignette would be given a B score of .875 ([1 + 1 + 1 + 0.5]/4).

Accordingly, the highest B score attainable was 1.0. The MCAST has shown good reliability and validity (Barone et al., 2009; Green et al., 2000). In the current study a random of 10% of the cases were recoded by blind raters, which resulted in a intra-class correlation coefficient (ICC) of .79 for the B-scale.

Parental emotional availability. To measure parental emotional availability we used the Emotional Availability Scales (EA; Biringen, 2000; Biringen, Robinson, & Emde, 2000). In this assignment the mother and the child is asked to use a set of wooden blocks to construct a chair and a house, portrayed in example pictures. The task is designed to be a bit too difficult for the child to solve alone. The mother is instructed to assist the child as she normally does. Interaction between parent and child is videotaped and coded. The EA has 6 subscales, 4 related to the parent (sensitivity, structuring, nonitrusivness and nonhostility) two related to the child (responsivnes to the parent and involvement of the parent). In this study we used a sum score computed by the subscales related to the parent. The EA has shown to have substantial construct validity, and moderate reliability (Bornstein, Suwalsky, & Breakstone, 2012). The EA has previously shown good reliability in the present study (Wichstrom et al., 2013).

Socioeconomic status. To measure socioeconomic status we used a measure of occupational status derived from the widely accepted International Standard of Classification of Occupations (ISOC-88; Elias, 1997).

Results

All statistical analysis where conducted using Mplus Version 6.0 (Muthén & Muthén, 2010). Robust maximum likelihood estimator was used. The robust maximum likelihood estimator is based on corrected statistics obtainable with the maximum likelihood method and is robust for mild deviations from normality (Raykov & Marcoulides, 2006). Full information likelihood was applied to handle missing data thus, values that are missing are not imputed, all data that are available are used to estimate the model. Table 2 shows descriptive statistics for the executive function tasks. Children's performance improved significantly over time on the digit span (χ^2= 15.54, DF=1, p=.001) and on set shifting EDS errors (χ^2= 4.50, DF=1, p=.03). There was no significant improvement in inhibition (χ^2= 1.07, DF=1, p=.30) or in set shifting total errors adjusted (χ^2=2.5, DF=1, p=.11).

Correlation analyses were conducted to test the relationship between all outcomes and predictor variables(Table 3). Socioeconomic status and gender did not correlate with baseline executive functions, and was therefore not included as covariates in the further analyses. Correlations among predictors were only found between parent's emotional availability and attachment. Attachment was also correlated with inhibition. No other predictor was correlated with outcome at the age of 6.

To examine the stability in executive functions from age 6 to 8, regression analysis was applied. The score on each executive outcome (e.g. IED total errors adjusted) at age 8 was regressed on the score on the same executive measure at age 6. The stability of the executive functions was low for inhibition (β=-.05, p=.473) and set shifting (total errors adjusted: β=.07, p=.118; EDS errors: β= .08, p=.067), only the stability of working memory reached significance (β=.14, p=.001).

Growth modeling was applied to examine predictors of change in executive function. Growth modeling is a technique for modeling within-person change across repeated measures and between-person differences in those changes (Grimm & Ram, 2009). To be able to use growth analysis with measures of executive functions from only two time points, residuals were fixed to zero. Hence, growth factors were treated as observable variables. Growth analysis yields two factors; intercept and slope. In this study the intercept was defined as the growth starting point, and is thus identical to the baseline value (executive function at age 6). The slope represents the change from 6 years to 8 years. The slope and the intercept were regressed on attachment, emotion regulation, parental sensitivity, and stress. In addition the slope was also regressed on the intercept. All these covariates were allowed to correlate. More specifically, one model was tested for each of the four executive measures (the statue-test, digit span, total errors adjusted, EDS errors) with the same predictor variables included in all four models tested. Table 3 presents the results of the growth analyses, exploring emotion regulation, secure attachment, emotional availability and major stressful life event as predictors of change in executive functions. As can be seen, attachment significantly predicted the intercept of both inhibition and set shifting 1. Stress had a significant effect on the slope of the two measures of set shifting. Potential interactions between the predictors were also tested, but no such effect was found. Bivariat analyses were conducted to examine the predictive effect of each predictor. No difference in prediction was found between the bivariate analysis and the full model analysis, thus only the latter is reported.

Discussion

The aim of the current study was twofold: To examine the stability of executive functions from the age of 6 to 8 and to explore predictors of change in executive functions in a large community sample of 6 year olds followed up at age 8. The results showed that working memory was modestly stable, whereas inhibition and shifting were not stable. It was further found that children who had experienced major stressful life events at age 6 or earlier had diminished increase in executive functions at age 8 compared to agemates with no or fewer events. Attachment was significantly associated with executive functions at age 6, but did not predict change from age 6 to age 8.

In support of the hypothesis, the measures of executive functions showed very low stability in the present study. Working memory was the only executive function of those explored, that turned out to be stable between the two points of measurement. Of the few studies conducted on this topic, several have reported low or non-significant stability of working memory in children. Hammond et al. (2012) reported non-significant correlations between working memory measured at age 2 and 3 respectively. Hughes et al. (2013) also found non-significant stability in executive functions from 2 to 4 years of age. Polderman et al. (2007) reported low stability in working memory between the age of 5 to 12. Few studies have investigated the stability of inhibition and set shifting in children using the same measures repeatedly. This is unfortunate, because a problem when it comes to tests of executive function is that the test applied inevitably will measure something more than pure executive functions; it can for instance measure auditory, and or verbal processing, along with motor or verbal response, and response time, and a test can measure more than one forme of executive functions at the same time. This has been termed the task impurity problem (Miyake et al., 2000). The use of different measures of executive functions in longitudinal studies can distort the assessment of stability if the measures applied rely on different additional processes. The present study uniquely measured working memory, inhibition and set shifting at the age of 6 and 8 using the same measures at the two points in time, providing important insight into the stability of executive functions in children.

The present findings on stability of executive functions in children are intriguing. They contrast findings in adolescents (Boelema et al., 2013; Friedman et al., 2012) and in older adults (Ettenhofer, Hambrick, & Abeles, 2006) showing substantial stability. The question then arises; why is the stability of executive functions low or non-existing in children when they are highly stable in late adolescents and older adults? Knowledge on the development of executive functions in children may provide possible answers to this question. Executive functions develop rapidly in childhood (P. Anderson, 2002), and the development is not necessarily linear as developmental regression also have been reported (P. Anderson, Anderson, & Lajoie, 1996; V. A. Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Thus, finding low stability may reflect a nonlinear and erratic development of executive functions in children. Further, different domains of executive function develop at different ages (Best & Miller, 2010), and there is evidence that inhibition develops early in childhood and that set shifting has a critical period of development between the age of 7 and 9 (P. Anderson, 2002). Thus, it could be prematurely to measure set shifting before the age of 7, which could explain the non-significant stability of set shifting in our study. These findings highlight the importance of investigating predictors of different executive functions separately, as they seem to be susceptible of influence at different ages.

It could further be hypothesized that the low stability found was due to measurement errors. However, adequate to high reliability is found both for the measure of inhibition (Brooks et al., 2009) and working memory (Müller, Kerns, & Konkin, 2012), used in this study, and all the data was collected using standardized procedure from the various protocols, which should minimize the chance of error.

The results showed that major stressful life events predicted change in executive functions from 6 to 8 years. This is in line with earlier research reporting stress to be negatively associated with executive functions (Berry et al., 2012; C. Blair et al., 2005; Clancy Blair et al., 2011). Notably though, to our knowledge no prior study has documented this effect on growth in executive function. Thus, it has not been clear whether weaker executive functions might lead children to seek more potentially stressful situations, or that stressful situations might affect executive functions in a negative direction. The current finding provides new insight by showing stress not only to be negatively related to executive functions, but to negatively predict *change* in executive functions. How can we explain such finding? Stress is related to two major neuroendocrine system; the autonomic nerve system (consisting of the sympathetic and the parasympathetic nerve system) and the hypothalamus-piuitary-adrenal (HPA) axis (Charmandari, Tsigos, & Chrousos, 2005). The hormonal end product of the HPA axis is cortisol. Both cortisol (C. Blair et al., 2005; Egeland et al., 2005) and parasympathetic functions (Kimhy et al., 2013) seem to have an effect on executive functioning. There are at least two, possible mechanisms through which major stressful life events may affect executive functions in children. One explanation is that because executive functions are higher order cognitive functions (Hofmann, Schmeichel, & Baddeley, 2012), these will arguably be affected by high levels of stress, as stress will be demanding of mental resources (Wegner, 1988). This is possibly what is observed in children and adults with PTSD, who have deficits in executive functions (Beers & De Bellis, 2002); the level of stress is so high that mental resources normally available to tasks requiring executive functions, no longer is, causing low scores on measures of executive functions. Another explanation, not necessarily excluding the first, is that major stressful events have long lasting effects on brain tissue. It is generally accepted that stress related hormones alter brain structures (Bremner, 1999; Sapolsky, 2000). In their review of the effect of stress on cognitive and affective functions, Pechtel and Pizzagalli (2011) concluded that stress experienced early in life can have especially long lasting negative effects on neurological functioning such as executive functions.

As previously mentioned, different forms of executive functions seem to develop at different ages (Best, Miller, & Jones, 2009) and it is found that set shifting seem to have a critical phase of development between the age of 7 to 9 (P. Anderson, 2002). This could explain why the present study showed an effect of stress on the change in set shifting from the age of 6 to 8 – a critical time of development for this ability – but no correlation between stress and set shifting at age 6 – when this ability has not yet started its developmental spurt. Future studies should investigate whether stress continues to affect the development of set shifting after the age of 8, to give further understanding of the developmental trajectory of set shifting.

The current results have some clinical implications. If major stressful life events can affect children's executive functions regardless of prior executive functions, this indicates that cautions are to be made by clinicians, school staff etc. when a child has experienced a stressful life event. Regardless of that child's prior executive functioning, the child's development of executive functions could suffer, and training programs (see Diamond & Lee, 2011) might be of use. Further, clinicians treating children for emotional problems caused by major stressful events should also devote attention to the possible cognitive impairments that may be present, and provide training if needed.

Major stressful life events were the only variable tested in the current study that significantly predicted the slope of executive functions. However, attachment positively predicted the intercept of inhibition and set shifting, which due to the use of only two measurement points corresponds to the baseline values of the respective executive functions. In other words, the more securely attached the child was, the higher the scores on inhibition and set shifting at age 6. Notably though, no conclusion can be drawn on the causality of this relationship. Bernier et al. (2012) found that attachment measured at 12 and 18 months predicted executive functions at age 3. A possible explanation for the discrepancy between the findings in the current study and the findings done by Bernier et al. (2012) is that executive functions are affected differently at different ages. Bernier et al. (2012) investigated change in executive functions from 18 months to 3 years. The attachment relationship between child and parent may be more salient for the toddlers than for school aged children, and this might explain our findings.

Given the low stability from age 6 to 8 in our study, one would expect the change in executive functions to be susceptible for the effect of both individual and environmental factors. It is therefore a bit surprising that major stressful life events was the only variable of those examined that significantly predicted the slope and thus the change in executive functions. It was especially surprising to find factors previously found to be associated with executive functions; socioeconomic status (Catale et al., 2012; Noble et al., 2007), parental sensitivity and support (Hammond et al., 2012; Samuelson et al., 2012) and child emotion regulation (Carlson & Wang, 2007; Simonds et al., 2007), not be associated with executive functions in the current study. However, Bernier et al. (2012) also found attachment but not parental sensitivity (resembeling emotional availability), to be associated with executive functions, and (Liebermann et al., 2007) did not find an association between emotion regulation and executive functions. It is possible that the mix results concerning factors related to executive functions in children also is a result of the erratic development of executive functions. Because studies conducted typically are cross-sectional, short in time span and/or do not adequately differentiate between different components of executive functions, the results will be contradicting because different factors will be associated with different subcomponents of executive functions at different ages.

It is further likely that other factors than those measured in our study might play a role in the development of executive functions. Importantly, genetic measures were not included in the present study. In an adoption study Leve et al. (2013) investigated the impact of both parental risk factors and genetic factors on the development of executive functions in children from 9 to 27 months. In this study parental risk did not have an effect when genetic influence was accounted for. We have not had the opportunity to separate genetic and environmental factors in our study. Considering the theories of Belsky (1997, 2005) and Boyce and Ellis (2005; 2011) which states that different children are affected by environmental factors in different ways, it is crucial to explore how children with different genotypes responds differently to environmental factors, and how this effects executive function. However, it is argued that genetic factors contributes more to stability than change (Kovas, Haworth, Dale, & Plomin, 2007). Thus, the fact that we observed little stability in executive functions, would indeed indicate that environmental factors affect change, although the current study was not able to contribute the positive identification of such factors.

As different forms of executive function often are reported to be strongly correlated (M. R. Miller et al., 2012; van der Ven et al., 2013), it was somewhat surprising to find such low correlations as we did in our study. However, several other studies have also found low, and non-significant, correlations among different measures of executive functions in children (Brydges et al., 2012; Jacobson, Williford, & Pianta, 2011; Lehto et al., 2003; Wiebe et al., 2011). Senn, Espy, and Kaufmann (2004) found that performance on set shifting tasks was unrelated to performance on tasks of working memory and inhibition, and Rose et al. (2011) report correlations ranging from -.01 to .39 for test of working memory, inhibition and set shifting, several of which were not-significant. This may be related to the aforementioned task impurity problem (Miyake et al., 2000). It has been pointed out that what kinds of tests you use can influence how much the tests will overlap because of the task impurity problem (M. R. Miller et al., 2012; van der Ven et al., 2013). In our study the test applied had quite different input and output characteristics. In the digit span test material is presented auditory and demands a verbal response, whereas the IED the material is visually presented and demands a motor response. In the soldier test from NEPSY the child is supposed to ignore any form of stimuli, and not give any response. One might suspect that the reason our measures had such a limited co-variation is due to the fact that they resemble one another to such a low extent. Another possible explanation for the low correlation between the different components of executive functions is that studies that have reported high correlations have few participants and that the high correlation because the low population size gives a larger standard error in the estimate. Indeed some smaller studies (M. R. Miller et al., 2012 ; N=129) have reported relative high correlations compared to larger studies (Jacobson et al., 2011 ; N=925), but the trend is not complete, van der Ven et al. (2013) report relatively high correlations in a rather large population of 211 children.

Further, the low correlation may be partially explained by the aforementioned fact that different components of executive functions develop at different ages. As the children in the present study was quite young (6 to 8 years), it is possible that the subcomponents of their executive functions was so differentially developed that correlation was not to be found.

Although the present study had many strengths, several limitations should be considered when interpreting the findings. Firstly, assessment of child emotion regulation abilities and experience of major stressful life events, were based on parents report, which might be somewhat biased (Fergusson, Lynskey, & Horwood, 1993; Stokes, Pogge, Wecksell, & Zaccario, 2011). The correlation between parent and teacher report on the ERC has been reported to be quite low (r=.24; Ramsden & Hubbard, 2002). In the present study only the parent report was included. Including teacher report of emotion regulation might have affected the results. Further, it might have strengthened the study if laboratory measures of emotion regulation were applied. However, one might question the ethics of manipulating the emotions of young children. Also, laboratory measures might not be as ecologically valid as parents' observation of everyday behavior.

Secondly, the present study only measured executive functions at two points in time. As executive functions have a rapid and erratic development, with different parts of the executive functions developing at different rates, the need for studies with a wider time-span is necessary. However, this study is one of very few investigating change in executive functions over time, making an important contribution.

Thirdly, because the study was conducted in Norway with the vast majority of participants being of Norwegian ethnicity (93%), the generalization to other populations must be done with caution. Further, 73 participants dropped out of the study between the two points of measurement, and although the drop-out was predicted by stress and parental emotional availability, their contribution was very low. Thus, although the possibility of selective attrition influencing the present findings – which would imply interactive effects involving stress and emotional availability – it seems unlikely that they would grossly alter the results reported herein.

In summary, this study aimed to explore the stability of executive functions in large and representative sample of children from the age of 6 to 8, and to investigate the predictive effect of attachment, parental emotional availability, stress, socioeconomic status and child emotion regulation on change in executive functions. The results showed that the stability of set shifting and inhibition was low between the age of 6 and 8. Major stressful life events at age 6 predicted a comparative decrease in set shifting at age 8. To our knowledge this is the first study to investigate the predictive power of stress on executive functions while controlling for baseline executive functioning.

Our findings highlight the importance of investigating predictors of different subcomponents of executive functions separately, as they have different developmental trajectories and show low correlations in childhood.

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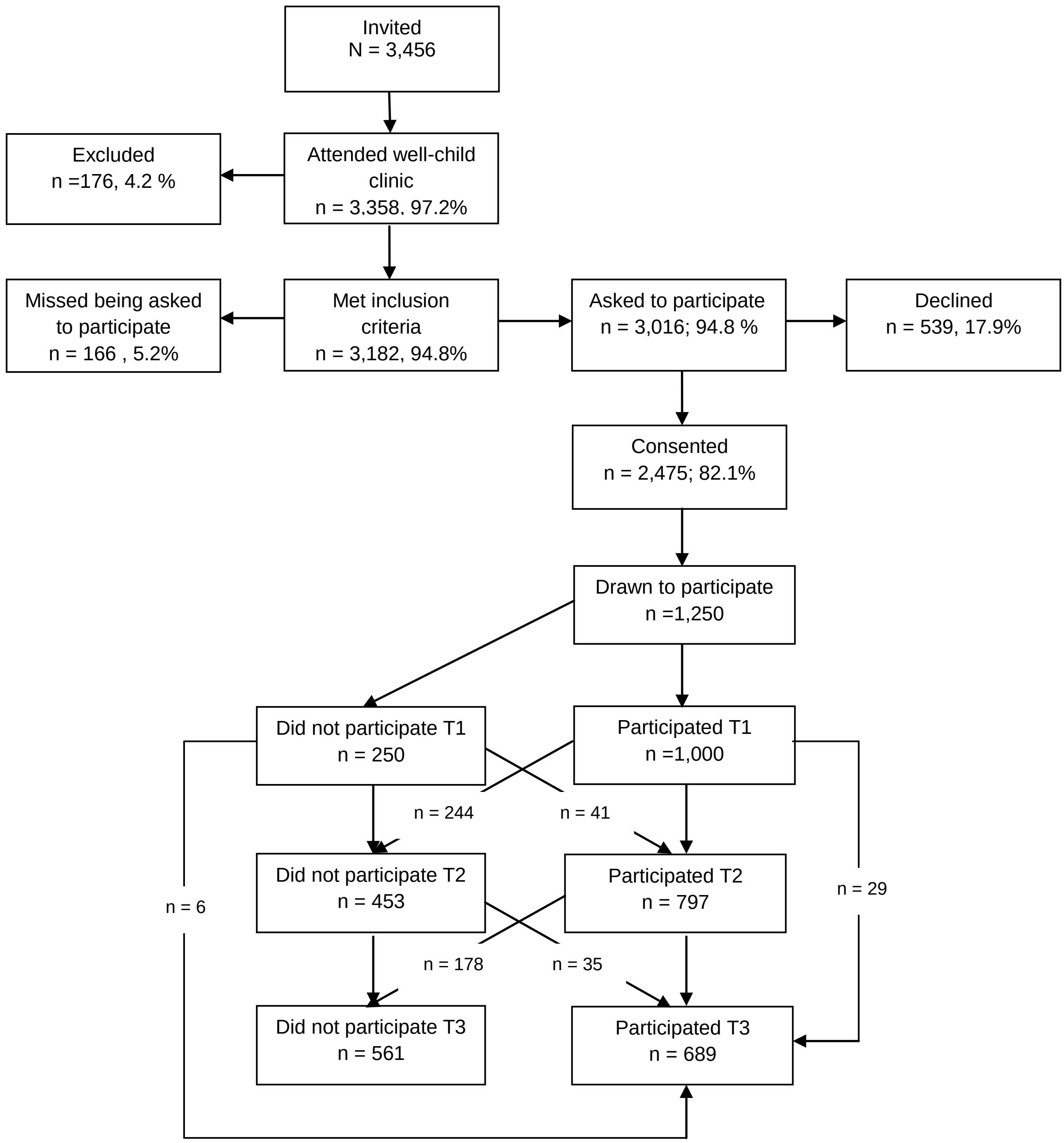

Figure 1. Sample recruitment

Table 1

Sample characteristics

Characteristics	%
Gender of child	
Male	49.8
Female	50.2
Gender of parent informant	
Male	18.9
Female	81.1
Ethnic origin of biological mother	
Norwegian	93.0
Western countries	6.8
Other countries	0.3
Ethnic origin of biological father	
Norwegian	93.0
Western countries	6.5
Other countries	0.5
Informant parent's socioeconomic status	
Leader	12.5
Professional, higher level	36.7
Professional, lower level	36.2
Formally skilled worker	14.1
Farmer/fishermen	0.0
Unskilled worker	0.6

Table 2

Means and standard deviations in executive functions at age 6 and 8

	Mean	S.D.
Working memory age 6	2.12	.07
Inhibition age 6	2.56	.08
Set shifting 1 age 6	2.05	.07
Set shifting 2 age 6	1.96	.06
Working memory age 8	5.73	.16
Inhibition age 8	4.73	.13
Set shifting 1 age 8	1.83	.06
Set shifting 2 age 8	1.81	.06

Note. Set shifting 1= Total errors adjusted, Set shifting 2= EDS errors.

Table 3

Correlations between measures of executive functions and predictors at 6 years

	Working memory	Inhibition	Shifting 1	Shifting 2	Emotion regulation	Secure attachment	Stress	EA
Working memory	-							
Inhibition	.171***	-						
Shifting 1	.015	-.039	-					
Shifting 2	-.017	.020	.270**	-				
Emotion regulation	.009	-.012	.033	.030	-			
Secure attachment	.057	.142**	-.094	.043	-.021	-		
Stress	-.070	-.005	.002	.029	-.032	.078	-	
EA	.063	.090	-.098	.018	-.038	.131**	.016	-

Note. Shifting 1= Total errors adjusted, Shifting 2= EDS errors, Stress= major stressful life event, EA= parental emotional availability.
**p<.01, ***p<.001

Table 4

Age 6 predictors of executive functions at age 8

Predictors	Outcome: Executive function at age 8											
	Working Memory			Inhibition			Set shifting 1			Set shifting 2		
	B	SE	β	B	SE	β	B	SE	β	B	SE	β
Emotion regulation												
Intercept	.090	.341	.011	-.010	.050	-.008	3.465	4.253	.029	1.339	1.818	.029
Slope	.015	.128	.003	.000	.005	.000	3.918	2.357	.049	.978	.989	.031
Secure attachment												
Intercept	.256	.248	.042	.114**	.042	.127**	-6.981*	3.322	-.080*	1.314	1.460	.039
Slope	.114	.114	.032	-.003	.005	-.006	.809	1.824	.014	-.159	.773	-.007
Stress												
Intercept	-.108	.075	-.066	-.010	.010	-.042	-0.047	0.971	-.002	-.211	.353	-.024
Slope	.019	.030	.020	.000	.001	-.004	1.149**	0.427	.073**	.537**	.199	.087**
EA												
Intercept	.009	.006	.058	.002	.001	.074	-.202	.119	-.088	.013	.038	.014
Slope	.003	.003	.028	.000	.000	.006	-.005	.053	-.003	.020	.021	.033

Note. Shifting 1= Total errors adjusted, Shifting 2= EDS errors, Stress= major stressful life event, EA= parental emotional availability.

*p<.05, **p<.01,