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The typical developmental trajectory of social and executive functions in late adolescence and early adulthood

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ABSTRACT

Executive functions and social cognition develop through childhood into adolescence/early adulthood and are important for adaptive goal-oriented behaviour (Apperly, Samson & Humphreys, 2009; Blakemore & Choudhury, 2006). These functions are attributed to frontal networks known to undergo protracted maturation into early adulthood (Barker, Andrade, Morton, Romanowski & Bowles, 2010; Lebel, Walker, Leemans, Phillips & Beaulieu, 2008) although social cognition functions are also associated with widely distributed networks. Previously, non-linear development has been reported around puberty on an emotion match to sample task (McGivern, Andersen, Byrd, Mutter & Reilly, 2002) and for IQ in mid adolescence (Ramsden et al., 2011). However, there are currently little data on the typical development of social and executive functions in late adolescence and early adulthood. In a cross sectional design, 98 participants completed tests of social cognition and executive function, Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), Positive and Negative Affect Scale (Watson, Clark & Tellegan, 1988), Hospital Anxiety and Depression Scale (Zigmond & Snaith, 1983) and measures of pubertal development and demographics at age 17, 18 and 19. Non-linear age differences for letter fluency and concept formation executive functions were found, with a trough in functional ability in 18 year olds compared to other groups. There were no age group differences on social cognition measures. Gender accounted for differences on one scale of concept formation, one dynamic social interaction scale and two empathy scales. The clinical, developmental and educational implications of these findings are discussed.

Keywords: adolescence, developmental trajectory, social cognition, executive function

INTRODUCTION

Adolescence represents a critical period of brain development for affective and social cognitive functions (Blakemore & Choudhury, 2006; Giedd, 2004; Giedd et al, 1999; Paus, Keshevan, Giedd, 2008; Sowell et al., 2003) characterised by hormonal upheaval, sexual maturation, and dynamic intellectual, emotional and social change set against a backdrop of increased peer influence (Forbes & Dahl, 2010; Sisk & Zehr, 2005; Wigfield, Byrnes & Eccles, 2006). Mid- to late-adolescence represents a time when the likelihood and incidence of engaging in risk-taking and injurious behaviour (including illicit drug use) is increased, more so than at any other age (Steinberg, 2008; Department for Education, 2011) indicating that intellectual, emotional and social development continue into late adolescence.

Researchers have mapped the normal developmental trajectory of the adolescent brain revealing protracted maturation particularly to frontal regions subtending numerous social cognitive functions (Sowell et al., 2003), including behavioural inhibition, impulse control, attentional switching (Barker, Andrade, Morton, Romanowski & Bowles, 2010; Stuss & Alexander, 2007; Collette, Hogge, Salmon & Van der Linden, 2006), attribution of mental states to others (Theory of Mind – ToM, Baron-Cohen, Leslie & Frith, 1985), emotion recognition (Beauchamp & Anderson, 2010; Blakemore, 2008) and perspective taking (Choudhury, Blakemore & Charman, 2006). Neuronal rewiring occurring mid- to late-adolescence is characterised by age-dependent fluctuations in white matter volume and synaptic pruning (reduced grey matter volume), a process thought to underpin increased functional connectivity between brain regions (Paus, 2005). Consequently, a dynamic picture of linear and non-linear neuronal re-organisation during late-adolescence has emerged, though data are needed to establish behavioural correlates of structural brain changes occurring during this period (Riddle et al., 2008; Lebel, Walker, Leemans, Phillips & Beaulieu, 2008; Gogtay et al., 2004; Yakovlev & Lecours, 1967).

Recent longitudinal data suggest that IQ undergoes substantial fluctuations in early to late adolescence possibly reflecting underlying neuronal re-organisation. Ramsden et al. (2011) reported a longitudinal study assessing IQ in adolescents aged 12-16 at Time 1 and 15-20 at Time 2. Participants showed variation in IQ scores between time points, with increases or decreases evident across adolescence (Verbal IQ -20 to +23, Performance IQ -18 to +17 and Full Scale IQ -18 to +21). Whether social and executive functions (functions important for autonomous and independent behaviour) follow linear and non-linear developmental trajectories corresponding to morphological brain change as claimed, remains to be established (Gogtay et al., 2004). However, there is mounting evidence from group (Barker et al., 2006, 2010) and longitudinal case study data that frontal trauma sustained prior to developmental and maturational plateaus of *late* adolescence/early adulthood produce graver deficits to socio-cognitive and executive functioning than injuries sustained later in adulthood (Anderson, Catroppa, Morse, Haritou & Rosenfeld, 2005; Anderson, Damasio, Tranel & Damasio, 2000; Anderson, Bechara, Damasio, Tranel & Damasio, 1999; Barlow, Thomson, Johnson & Minns, 2005; Eslinger, Biddle & Grattan, 1997; Tranel & Eslinger, 2000). Considered together findings provide indirect support that maturational brain change occurring in late adolescence has profound and enduring implications for social cognitive and executive abilities across adulthood.

Executive functions initiate, co-ordinate, maintain and inhibit subordinate cognitive functions (Miyake et al., 2000; Barker et al, 2010; Morton & Barker, 2010; Goldberg, 2001), and include the ability to plan, problem solve, allocate/switch attention, deal with novelty, and form concepts (De Luca et al., 2003; Strauss, Sherman & Spreen, 2006; Stuss & Alexander, 2000; Wilson, Alderman, Burgess, Emslie & Evans, 1996; Burgess, 1997; Shallice & Burgess, 1991). Imaging, lesion, case and group study data indicate that executive functions are subtended by frontal networks and follow protracted development into early adulthood corresponding to frontal brain maturation (Anderson et al., 2001; Huizinga, Dolan & van der Molen, 2006; Levin et al., 1991; Lin, Chen, Yang, Hsiao & Tien, 2000; Romine & Reynolds, 2005). Problems associated with executive function impairment in the school or work place in normal populations includes disorganization and inability to prioritise the importance of different tasks (Burgess, 2003).

Selective frontal brain networks are also thought to underpin certain aspects of social cognition with medial prefrontal networks, superior temporal sulci and temporal poles consistently implicated in social cognition task performance and referred to as the ‘mentalizing’ network (Blakemore, 2008; Carrington & Bailey, 2009; Castelli, Happé, Frith & Frith, 2000; Fletcher et al., 1995; Frith & Frith, 2006; Gallagher et al., 2000). Social cognition broadly is the ability to understand others’ behaviour using information from facial expressions, body movements, language and prosody (Carrington & Bailey, 2009). Tager-Flusberg (2001) proposed that social cognition comprises social-perceptual (understanding and interpreting information from faces, voices and body posture and attributing mental states), and social-cognitive (use of information and events over time to attribute mental states) components. Functions include emotion recognition, empathy and perspective taking (Frith, 2007), and Theory of Mind (ToM - Baron-Cohen, Leslie & Frith, 1985) the ability to impute a range of mental states, including beliefs, desires and intentions to self and others (Premack & Woodruff, 1978; Carrington & Bailey, 2009; Frith, 2007; Kalbe et al., 2010; Vollm et al., 2006; Beer & Ochsner, 2006). Poor social cognition skills in late adolescence or early adulthood can impede educational and vocational success and friendship formation potentially leading to isolation, anxiety and depression (Ahmed & Miller, 2011).

Recent work found that performance on a dynamic social cognition task (MASC - Dziobek et al., 2006) using fMRI with 20 to 45 year olds activated several independent but synchronous networks including occipito-parieto-temporal, lateral prefrontal, dorsomedial and precuneus regions associated with visuospatial, language and self-referential information processing respectively (Wolf, Dziobek & Heekeren, 2010). Therefore, executive function and social cognition show common yet distinct neural substrates depending upon the particular function(s) measured suggesting that some but not all aspects of social cognitive functioning might follow a similarly protracted developmental trajectory as executive functions.

Development of executive function ability

Preliminary data on maturation of executive function through childhood to adolescence and adulthood show conflicting findings. Romine and Reynolds (2005) analysed effect size differences across ages 5-8, 8-11, 11-14, 14-17 and 17-22 year old groups and proposed that executive functions develop at different rates, follow different developmental trajectories reaching optimal levels at different ages (Romine & Reynolds, 2005). Verbal fluency and planning ability (measured with the Tower of Hanoi) improved from 17 to 22 years. Planning accuracy peaked between 15-19 and 20-29 years of age, with rule violations lowest at 13-19 years (Delis, Kaplan & Kramer, 2001; De Luca et al., 2003). Other results are less clear-cut; inhibition of perseverative responses (Wisconsin Card Sorting Task performance – Heaton, Chelune, Talley, Kay & Curtiss, 1993) improved from 11 to 14 years of age with no additional improvement shown up to age cut-off (22 years). In contrast, Huizinga, Dolan and Van der Molen (2006) analysed cross-sectional data and found that performance accuracy on the WCST and Tower of London increased up to age 21 years (see also Lin, Chen, Yang, Hsiao & Tien, 2000). Overall findings suggest linear progressive improvement to executive function ability from adolescence to 22 years. However use of broad age ranges (17-22) might mask non-linear functional change (i.e. troughs as well as peaks in ability) occurring during this developmental period corresponding to rapid maturational change.

Development of social cognitive functions

There is contrasting evidence of linear and non-linear development of social cognitive functions across adolescence/early adulthood depending upon age at test and measure used. Dumontheil, Apperly and Blakemore (2010) found linear improvement from childhood to adolescence and adulthood on a spatial "Director" perspective-taking task. The adolescent group aged 14 to 17.7 years made more errors than the adult group aged 19.1 to 27.5 years although this difference was not significant. Other data also show a similar linear developmental trajectory on emotion measures. Participant scores on the Interpersonal Reactivity Index (IRI; Davis, 1983) self-report empathy measure were higher than baseline at one year follow up in a sample of 13 to 15 year olds, signifying improved cognitive and affective empathy (Mestre, Samper, Frías & Tur, 2009). Evidence for non-linear social cognitive development has been shown on a match-to-sample task utilizing faces and/or words categorised as happy, angry, sad or neutral (McGivern et al., 2002). The authors found that performance of 11-12 year old females and 12-13 year old males was poorer (indexed by a 10–20% increase in reaction times), compared to participants one year younger.

To summarise, in late adolescence there is rapid maturation of frontal networks considered to subserve executive functions necessary for independent and autonomous behaviour and some aspects of social cognitive ability. Although there are extensive child (Pennequin, Sorel & Fontaine, 2010), early adolescent (Prencipe et al., 2011) and adult data on executive function (Guevara, Martínez, Aguirre & González, 2012; Barker et al, 2010; Morton & Barker, 2010; Barker et al; 2006) and social cognition (Dziobek et al, 2006., Heavey et al., 2000., Dumontheil, Apperly & Blakemore, 2010) measures with normal and pathological groups, there is scant data for fine-grained age ranges in late adolescence on measures of executive function and social cognition. Of note there is mounting evidence that dynamic brain plasticity in late adolescence confers vulnerability for first episode psychiatric illness (Paus, Keshavan, & Giedd, 2008) and this population is also highly represented in brain-injury demography, probably due to increased risk taking and drug use at these age ranges. Consequently, it is important to establish normative social and executive function data across the important maturational period of late adolescence.

The present cross sectional study investigated the functional developmental trajectory of executive and social cognitive functions in three groups of typically developing adolescents aged 17 years 0 months – 17 years 8 months, 18 years 0 months – 18 years 8 months and 19 years 0 months – 19 years 8 months. Fine-grained age groups were selected on the previous recommendation that broad age groups decrease sensitivity (De Luca et al., 2003). We expected to find age effects on socio-cognitive and executive function tasks based on current morphological and behavioural data.

METHOD

All participants gave written informed consent (parental consent for participants < 18 years). Participants were recruited from local schools, colleges, youth organisations and universities. Head injury was an exclusion criterion because of its impact on executive function (Barker et al., 2010) and social cognition (Martín-Rodríguez & León-Carrión, 2010) at these age ranges. Standardised and broadly used measures of social cognition and executive function were selected on the basis of previous studies (Morton & Barker, 2010; Romine & Reynolds, 2005), and data showing that particular functions are associated with frontal networks that undergo rapid maturational change at these age ranges (Apperly, Samson & Humphreys, 2009; Blakemore & Choudhury, 2006; Barker et al; 2010; Sowell et al., 2003).

Self-report measures were used to assess extent and type of drug use by participants because drug use affects executive (McHale & Hunt, 2008) and social functions, and it is not possible to completely screen out drug use in adolescence. We developed a demography measure assessing education, employment, change to living arrangements and friendship groups over the preceding year to account for any effects of environment on functional change. Participants were asked to report current mental illness and mood state because this may have affected task performance, although current findings are equivocal in relation to mood state and cognitive function (Uekermann et al., 2008; Favre et al., 2009).

The Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999) provided Full-Scale IQ, Performance and Verbal indices. The Positive and Negative Affect Scale (PANAS; Watson, Clark & Tellegen, 1988) and The Hospital Anxiety and Depression Scale (HADS; Zigmond &

Snaith, 1983) measured mood state and anxiety and depression respectively. We also included the Self-Administered Rating Scale for Pubertal Development (Carskadon & Acebo, 1993) because the role of hormones is often overlooked in developmental research (Kalkut, Han, Lansing, Holdnack & Delis, 2009; Blakemore, 2008).

Participants

The sample consisted of 98 participants in total from three age groups: 17 years 0 months – 17 years 8 months (*n* = 31, *M* = 17years 4 months, *SD* = 2.5 months, 23 females: 8 males), 18 years 0 months – 18 years 8 months (*n* = 31, *M* = 18 years 4 months, *SD* = 2.4 months, 26 females: 5 males) and 19 years 0 months – 19 years 8 months (*n* = 36, 19 years 2 months, *SD* = 1.7 months, 28 females: 8 males). More females (*n* = 77) than males (*n* = 21) volunteered for the study, although the gender ratio was broadly balanced across the age groups and we account for the gender bias in statistical analyses.

Procedure

Participants completed the questionnaire measures and the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999) prior to the executive and social cognition task battery. The social cognition and executive function tasks were counterbalanced across testing sessions, which were approximately 3 hours in duration. Rest breaks were participant-determined.

Executive function measures

The Verbal Fluency (Letter) measure of response generation, the Sorting Test, a measure of problem solving, abstract concept formation and perseveration and the Tower Test, a measure of planning, were selected from the Delis Kaplan Executive Function System (Delis et al., 2001). In the Verbal Fluency (Letter) Test, participants are asked to generate as many words as possible beginning with the letters ‘F’, ‘A’, and ‘S’, in one minute per category. The D-KEFS Sorting

Test comprises free sorting whereby participants are asked to sort 6 cards into 2 groups and describe the characteristics of each group. There are 8 possible sorts; three sorts use semantic information of words (e.g. animals vs. transport) and 5 sorts use perceptual features of the cards (e.g. shape or colour). The sort recognition condition requires participants to identify how the examiner has sorted the 6 cards into 2 groups. The D-KEFS Tower Test requires participants to complete a specified goal by moving discs from one ‘tower’ to another as quickly as possible and without breaking specific rules.

The Hayling subtest of the Hayling and Brixton tests (Burgess & Shallice, 1997) provides a measure of inhibition of prepotent responses as maturation of inhibition in adolescence is not well understood (Luna & Sweeney, 2004). Sentences are read aloud and participants are required to complete the sentence with an appropriate word. Participants are instructed to complete the sentences correctly in the first part of the task and then produce a word completely unconnected to the sentence in the second part of this task, thus requiring them to inhibit previous prepotent responses. The Brixton test, a measure of rule or concept attainment in a visuospatial format, requires participants to identify the pattern followed by a coloured circle embedded in an array of blank circles based on subsequent page turns. The pattern followed by the circle changes several times and successful task completion requires participants to detect each new pattern. The outcome measure is the total number of errors from 55 trials.

Social cognition measures

Social cognitive tasks were selected in line with the conceptualisation that social cognitive functions are predominantly social-perceptual or social-cognitive (Tager-Flusberg, 2001). The Reading the Mind in the Eyes (Baron-Cohen et al., 2001) and Reading the Mind in the Voice (Golan, Baron-Cohen, Hill & Rutherford, 2007) tasks provided measures of social-perceptual processes, whereas the Movie for the Assessment of Social Cognition (Dziobek et al., 2006) assessed both social-perceptual and social-cognitive processes. An alternative framework views social cognition as processes involved in understanding other people and understanding the self (Beer & Ochsner, 2006). Thus, the inclusion of a self-report empathy measure assessed the self-understanding component of social cognition.

The Reading the Mind in the Eyes Test measures emotion recognition with static visual stimuli of a person's eye region and requires participants to choose one from four complex mental state terms which best describes what the person is thinking or feeling. Total test scores range from 0 to 36. The Reading the Mind in the Voice Test, comprised of 25 sound clips drawn from television dramas, was selected to measure emotion recognition in an auditory domain. Participants are required to choose one of four complex mental states that best describe how the speaker is feeling based on verbal content and the speaker's intonation. Total test scores range from 0 to 25. We also selected the Movie for Assessment of Social Cognition (Dziobek et al., 2006) to provide an ecologically valid measure of dynamic social cognition in naturalistic settings (Heavey, Phillips, Baron-Cohen & Rutter, 2000). The MASC consists of a 15 minute film depicting social interaction between four adults and is paused 45 times with participants answering questions about a character's feelings, thoughts and intentions. The task requires participants to detect first and second order false belief, deception, faux pas, persuasion and sarcasm. Scores range from 0 to 45, with each question having a four item forced choice answer format. The four possible answers include the target answer, responses in which the mental state inference is excessive or insufficient, and an answer that lacks mental state inference instead referring to physical causation.

The Interpersonal Reactivity Index (IRI; Davis, 1983) was chosen to measure empathy, an important element of adaptive social cognition. The IRI is a 28 item self-report measure indexing four aspects of empathy: empathic concern, personal distress, perspective taking and fantasy. Participants rate statements on a five-point scale as to how well they describe themselves, ranging from 0 “does not describe me well” to 5 “does describe me well”. All stimuli were presented in English.

RESULTS

Participant IQ and demographic data

Descriptive statistics for IQ and demographic data are presented in Table 1. There were no significant group differences on Full Scale IQ or Verbal IQ. Groups differed on Performance IQ (F (2, 95) = 3.24, p = 0.04), with 18 year olds scoring significantly lower than 17 year olds (t (60) = 21.3 p = 0.04) and 19 year olds (t (65) = 2.30 p = 0.03), although mean IQ scores for each group all fell within the average range. Reported mental illness was similar across age groups. Extent of pubertal development differed between groups (F (2, 95) = 9.10, p<0.01). Seventeen year olds scored lower than 18 year olds (t (95) = 3.03, p < 0.01) and 19 year olds (t (95) = 3.06, p < 0.01) indicating that the youngest age group had less pubertal development than the other groups as expected. There were no other group differences for pubertal development.

There were no significant group differences on the Positive Affect scale of the PANAS measure of mood state (Watson, Clark & Tellegen, 1988). Group differences were seen on the Negative Affect scale of the PANAS (F (2, 95) = 5.04, p<0.01), with seventeen year olds (t (65) = 2.91, p<0.01) and eighteen year olds (t (65) = 2.88, p<0.01) scoring significantly higher than 19 year olds. The PANAS scores are similar to normative data collected by Crawford and Henry (2004) indicating that group differences did not reflect pathological changes to mood state. There were no group differences on the Depression scale of the HADS (Zigmond & Snaith, 1983). Group differences were found on the Anxiety scale of the HADS (F (2, 86) = 3.49, p = 0.04), with scores for 17 year olds and 18 year olds within the mild anxious range and significantly higher than 19 year olds whose scores were in the normal range, although anxiety scores were not at clinically significant levels. The age groups were broadly comparable on mood state, anxiety and depression scores. Self-report of previous cannabis use (F (2, 95) = 2.35, p = 0.10), ecstasy use (F (2, 95) = 0.22, p = 0.80) and alcohol use (F (2, 95) = 1.88, p = 0.16) were similar across age groups.

The 19 year old group in the current study had greater independence from family, with 75% reporting they lived with housemates instead of parents compared to 0% of 17 and 65% of 18 year olds. Seventy five percent of 19 year olds reported their living arrangements had changed in the last year compared to 16% of 17 and 68% of 18 year olds indicating that 18 and 19 year old groups had undergone greater change to their social and living environment than 17 year olds. A similar percentage of participants reported making new friends across 17 (42%) and 18 year old (45%) age groups; this was greatest in 19 year olds (67%), presumably as a result of changed living arrangements. Seventeen year olds were studying for AS levels (45%), traditionally studied between the ages of 16 and 17, A2 levels (52%), usually studied between the ages of 17 and 18 in the UK before starting university, although it is also possible for adults to complete these qualifications, and BTEC (3%) (Business & Technology Education Council) a vocational work-related qualification, completed at age 16 or older. A higher percentage of 18 and 19 year olds were university students (81% and 97%).

Age group comparisons

Descriptive statistics for executive function and social cognition tasks are presented in Tables 2 and 5 respectively. One-way between group ANOVAs were conducted to identify group differences on raw scores of executive function and social cognition tasks. All *p* values are reported as two tailed throughout unless otherwise stated.

[Insert Table 2 here]

Executive function measures

Response inhibition and rule detection (Hayling & Brixton Tests) and response generation (D-KEFS Letter Fluency Test)

No significant age group differences on the Hayling Test, a measure of response inhibition (F (2, 95) = 2.23, p = 0.11) or Brixton Test, a measure of rule detection (F (2, 95) = 0.13, p = 0.88) were found. There were significant age group differences for scores on Letter Fluency (F (2, 95) = 3.70, p = 0.03) a measure of response/strategy generation. Results of post hoc Tukey tests showed that 17 year olds scored more highly, indicating better performance, than 18 year olds on the Letter Fluency task (t (95) = 2.69, p = 0.02). There were no significant differences between 17 year olds and 19 year olds (t (95) = 1.72, p = 0.20) or 18 and 19 year olds (t (95) = 1.07, p = 0.53).

Concept formation (D-KEFS Sorting Test)

There were a number of significant age group differences on the Sorting Test measure of concept formation. For number of correct free sorts (F (2, 95) = 4.58, p = 0.01), 17 year olds scored significantly higher than 18 year olds (t (95) = 2.69, p = 0.02) and 19 year olds (t (95) = 2.59, p = 0.03). Scores for 18 year olds and 19 year olds were not significantly different (t (95) = 0.20, p = 0.98). On free sort description score (F (2, 95) = 3.87, p = 0.02), 17 year olds (M = 45.23, SD = 7.66) scored significantly higher than 18 year olds (t (95) = 2.73, p = 0.02). There were no significant differences between 17 year olds and 19 year olds (t (95) = 1.87, p = 0.15) or 18 and 19 year olds (t (95) = 0.96, p = 0.60) on this variable. For the sort recognition description score (F (2, 95) = 3.81, p = 0.03), 17 year olds scored significantly higher than 18 year olds (t (95) = 2.54, p = 0.03). There were no significant differences between 17 year olds and 19 year olds (t (95) = 2.24, p = 0.07) or 18 year olds and 19 year olds (t (95) = 0.38, p = 0.92) on sort recognition description score. For the description score for perceptual sorts (F (2, 95) = 4.37, p = 0.02), 17 year olds scored higher than 18 year olds (t (95) = 2.37, p = 0.05) and 19 year olds (t (95) = 2.74, p = 0.02). Scores for 18 year olds and 19 year olds were not significantly different (t (95) = 0.29, p = 0.96) on this variable. There were no significant age group differences for description score for verbal sorts (F (2, 95) = 1.26, p = 0.29).

Raw data was transformed into standardised z scores to graphically illustrate peaks and troughs in task performance where group differences were evident (see Figure 1). Figure 1 shows z-score plots for Letter Fluency and Sorting Tests by age group. Graphed data follow a U shape suggesting non-linear development of concept formation and strategy generation with a peak at age 17, dip in performance at age 18 and slight upturn in ability on these measures in the 19 year old group.

[Insert Figure 1 here]

Measures of planning (D-KEFS Tower Test)

Several indices were calculated for the Tower Test according to the D-KEFS manual: number of items completed, achievement score (takes into account if items are passed and also the number of moves), mean first move time (total first move time / items administered), time per move (total completion time / total number of moves) and move accuracy (total number of moves / total minimum number of moves required). There were no age group differences for number of Tower items completed (*F* (2,95) = 0.98, *p* = 0.38), Tower achievement score (*F* (2,95) = 0.60, *p* = 0.55), Tower mean first move time (*F* (2,95) = 2.87, *p* = 0.06), Tower time per move (*F* (2, 95) = 0.81, *p* = 0.45) and Tower move accuracy (*F* (2,95) = 0.44, *p* = 0.64). These results indicate that ability on these measures did not differ significantly as an effect of age in late adolescence in the present cohort.

To explore a possible contribution of IQ to executive function performance, Full Scale IQ scores were entered as a covariate for tasks showing significant group differences. With Full Scale IQ partialled out, number of correct Free Sorts (*F* (2, 94) = 3.49, *p* = 0.03) and description score for perceptual sorts (*F* (2, 94) = 3.56, *p* = 0.03) from the D-KEFS Sorting Test remained significant. Letter fluency (*F* (2, 94) = 2.52, *p* = 0.09), description score for free sorts (*F* (2, 94) = 2.76, *p* = 0.07), sort recognition description score (*F* (2, 94) = 2.68, *p* = 0.07) and description score for verbal sorts (*F* (2, 94) = 0.61, *p* = 0.55) were not significant. Results indicate a contribution of IQ to response generation performance on the Letter Fluency task but not to correct free sorts and description score for perceptual sorts on the Sorting Test. It is important to note that IQ was not different across groups.

Pubertal Development and Changes in Living Arrangements.

The whole sample was divided into participants who had completed puberty and those who had not according to self-report scores on the Rating Scale for Pubertal Development to assess effects of puberty on cognitive function (Carskadon & Acebo, 1993). Independent samples t-tests showed no group differences on any executive (all *p*’s > 0.27) or socio-cognitive tasks (all *p*’s > 0.17), indicating that different level of pubertal development between groups did not mediate task performance.

We conducted two separate hierarchical multiple regressions to explore the contribution of age, living changes and anxiety to strategy generation and concept formation using scores on the Letter Fluency and Card Sorting Tests (number of free sorts correct) as criterion variables. 'Age' was entered in block one, 'changes to living arrangements' in block two and 'anxiety scores' in block three (see Tables 3 and 4). In block one, age was a significant predictor and accounted for 19% of variance in response generation. The addition of changes to living arrangements in block 2 and anxiety in block 3 resulted in models that did not significantly predict variance on the Letter Fluency Task. Age was a significant predictor of number of free sorts correct and accounted for 25% of variance. The addition of changes to living arrangements in block two showed that age was the only significant predictor. No predictor variables significantly predicted number of free sorts correct with the addition of anxiety scores in block 3. These findings indicate that age contributes more to strategy generation (D-KEFS Letter Fluency Task) and concept formation (D-KEFS Sorting Test) than changes in living arrangements and anxiety.

[Insert Tables 3 and 4]

Social Cognition Measures

Raw scores on social cognition tasks were analysed with one-way between group ANOVAs across age groups. Descriptive statistics are presented in Table 5.

[Insert Table 5 here]

One way between group ANOVAs showed no significant group differences on social cognition tasks including the Reading the Mind in the Eyes Task (F (2, 94) = 0.52, p = 0.59), Reading the Mind in the Voices task (F (2, 95) = 0.06, p = 0.94), total score of the Movie for the Assessment of Social Cognition (F (2, 95) = 0.29, p = 0.75), MASC excessive mental state inference errors (i.e. over-attribution of mental state content) (F (2, 95) = 1.19, p = 0.31), MASC insufficient mental state errors (i.e. under-attribution of mental state content) (F (2, 95) = 0.35, p = 0.70) and MASC no Theory of Mind errors (i.e. physical causation, no mental state attribution) (F (2, 95) = 0.83, p = 0.44). Finally there were no group differences on the four factors of the self-report empathy measure, the Interpersonal Reactivity Index (Davis, 1983): Fantasy (F (2, 94) = 0.87, p = 0.42), Perspective Taking (F (2, 94) = 0.01, p = 0.99), Empathic concern (F (2, 94) = 0.75, p = 0.48) and Personal distress (F (2, 94) = 1.38, p = 0.26).

Comparison with existing adult data

A summary of how executive function and social cognition change between late adolescence and adulthood based on published normative data is presented in Tables 5 and 6. [Insert Table 6 here]. Data suggest that some functions peak in late adolescence (Hayling Test: response inhibition and achievement score, mean first move time, time per move and move accuracy on the D-KEFS Tower Test) while other functions peak later in adulthood (Brixton Test: rule detection, D-KEFS Letter Fluency: response generation and D-KEFS free sorts correct: concept formation).

Gender differences

The present study included more females than males so group data were collapsed to provide two subgroups: females (n = 77) and males (n = 21) to explore any potential gender differences on tasks. Due to uneven sample sizes, Mann Whitney U tests were conducted to compare task performance across males and females. Results showed a significant difference for description score of perceptual sorts, a measure of concept formation (U = 576.50, Z = 2.01, p = 0.04) with males (median = 61.0, range = 25.0) scoring higher than females (median = 58.0, range = 46.0). There were no other significant differences on executive function task scores (all other p's >0.07).

For social cognition measures, there were significant differences on MASC total score (Dziobek et al., 2006), a measure of Theory of Mind using dynamic stimuli (U = 553.00, Z = 2.23, p = 0.03), with females (median = 36.00, range = 19.00) scoring slightly higher than males (median = 35.00, range = 11.00). Females (median = 5.00, range = 12.00) scored significantly lower than males (median = 6.0, range = 9.0) on MASC excessive mental state inference errors (i.e. over-attribution of mental state content) U = 510.50, Z = 2.60, p < 0.01. Results of Mann Whitney tests also showed differences on two indices of the Interpersonal Reactivity Index, a self-report measure of empathy: Empathic Concern (U = 519.50, Z = 2.45, p = 0.01) and Personal Distress (U = 440.00, Z = 3.15, p < 0.01). Empathic concern assesses sympathetic feelings to others and was higher in females (median = 21.00, range = 13.00) than males (median = 19.00, range = 11.00). Females (median = 14.50, range = 24.00) also rated themselves higher in Personal Distress than males (median = 10.00, range = 16.00), indicating that females report experiencing more anxiety than males in tense social situations. There were no other gender differences on the social cognition measures used here (all other p's > 0.47).

To conclude, results indicate that gender accounted for differences on one scale of executive function (males performed better than females) and one measure of social cognition (females performed better than males), together with two empathy subscales. The age groups were broadly comparable on potential confounding variables of Full Scale IQ, mood state, anxiety and drug use suggesting that age was driving group differences on executive function measures overall and gender rather than age accounted for differences on social cognition tasks.

DISCUSSION

Three age groups (17, 18, 19 year olds) completed a comprehensive battery of tests including IQ, social and executive function tasks and measures of affect, pubertal development and demographics. Full Scale IQ scores were similar across age groups indicating that differences in intelligence did not account for observed group differences on executive function measures, although additional analyses found that IQ mediated some aspects of Letter Fluency task performance, a measure of strategy generation. Different levels of pubertal development between age groups did not mediate performance on executive function and social cognition tasks. Drug and alcohol use was similar across groups, whilst negative mood state and anxiety were slightly lower in the two younger age groups. Our findings show evidence of age differences suggesting a possible non-linear trajectory for development of response generation and concept formation specifically between 17 and 18 years.

The executive functions of strategy generation and concept formation measured by the D-KEFS Letter Fluency and Sorting Test respectively showed age differences, with functional peaks shown in the 17 year old group compared to 18 and 19 year olds on Letter Fluency and better performance in 17 year olds compared to 18 year olds on most indices of concept formation. Successful performance on the D-KEFS Letter Fluency task requires participants to generate an effective strategy or mnemonic to retrieve words beginning with the specified letter. Our finding of IQ contributing to response generation performance on the Letter Fluency task is consistent with previous research (Diaz-Asper, Schretlen & Pearlson, 2004; Harrison, Buxton, Husain & Wise, 2000; Porter, Collins, Muetzel, Lim & Luciana, 2011), but IQ differences were not responsible for age group differences on executive tasks because groups were not different on the IQ task.

There were significant group differences on several indices of the Sorting Test task with 17 year olds scoring significantly higher, showing better concept formation skills, than 18 year olds on four components of concept formation (number of correct free sorts, free sort description score, sort recognition description score and description score for perceptual sorts). Seventeen year olds also scored significantly higher than 19 year olds on number of correct free sorts and description score for perceptual sorts. Thus 18 year olds showed a significant dip in performance across all indices of the sorting test compared to their younger counterparts but were not significantly different from 19 year olds. There were no group differences on description score for verbal sorts index of the Sorting Test suggesting that the separate indices of the task are functionally dissociable. Groups may have performed similarly on this index because performance is associated with verbal aptitude and groups were not different in this respect on the basis of IQ subscales scores.

Future data collection with 16 year olds and comparison with adult data would elucidate whether functions mature, diminish or plateau between 16 and 17 years. Comparing the present late adolescent data with existing adult data reveals different developmental trajectories for selective functions. Performance peaks in late adolescence for emotion recognition with static visual stimuli, emotion recognition with dynamic stimuli, response inhibition and several indices of planning (Tower achievement score, mean first move time, time per move and move accuracy). Faster mean first move times and time per move in late adolescence possibly indicate some degree of impulsivity in this age group relative to adults. Emotion recognition from auditory stimuli, rule detection, response generation and one index of concept formation (number of correct free sorts) continue to develop into adulthood.

It is possible poorer performance at age 18 reflects dynamic brain changes to regions underpinning specific executive functions and corresponds to morphological evidence of synaptic pruning occurring in prefrontal networks following age 17 shown in imaging data (Gogtay et al., 2004). Non-linear development may reflect several dynamic maturational processes including synaptic pruning, increased white matter connectivity (Lebel et al., 2008; Paus, 2005; Sowell et al., 2003) and functional synchronization (Uhlhaas et al., 2009). Environmental changes may also possibly play a possible role in executive function development in late adolescence; 18 and 19 year olds had undergone greater changes in living arrangements relative to 17 year olds. Regression analyses indicated that changes to living arrangements accounted for approximately 10% of variance in strategy generation and concept formation although the contribution of this variable to executive function was not significant and age accounted for the greatest variance.

Groups were not different on the Tower Test measure of planning. Other data similarly show little behavioural differences on this measure across broad age ranges, although EEG data indicated age effects in neural networks underpinning task performance. Guevera, Martínez, Aguirre and González (2012) reported no significant differences for first move time and number of moves on the Tower of Hanoi in 11-13 year olds, 18-20 year olds and 26-30 year olds. The older groups completed significantly more towers in the time limit relative to 11-13 year olds. EEG during task performance showed age differences in coupling between prefrontal and parietal regions. Therefore, it is possible that group differences on the Tower Test in late adolescence are only evident with EEG. Other findings show that performance on a computerized version of the Tower of London task is associated with activation in frontal, parietal and premotor networks suggesting diverse neural substrates mediate performance on this measure (Wagner, Kock, Reichenbach, Sauer & Schlosser, 2006). Thus, it is likely that performance on the Tower Test recruits functions mediated by diverse neural substrates and that might account for the absence of significant group differences on the task.

Surprisingly no effect of age was found for social cognition measures, although gender mediated fours aspects of social cognition. Other research has similarly reported non-linear development of emotional processing for faces or words in early adolescence (McGivern et al., 2002), and linear development on a perspective-taking task (Dumontheil et al., 2010). Although speculative it is possible that the functions measured in the current study are well established by late adolescence. Findings indicate diverse neural substrates, including occipito parietotemporal, temporal and prefrontal networks, contribute to performance on the MASC (Wolf et al., 2010). There is also extensive evidence from imaging data that myelination follows a specific template across development occurring in a posterior to anterior direction (Kinney, Karthigasan, Borenshteyn, Flax, & Kirschner, 1994; Lebel et al., 2008; Sowell et al., 2003; Yakovlev & Lecours, 1967) so that occipital networks and posterior frontal networks mature earlier than anterior networks which continue to mature until around age 25 (Sowell et al., 2003). Consequently current data indicate that social cognitive functions measured here are relatively stable across late adolescence. Future studies might measure behavioural and imaging data to further establish how maturational change impacts cognitive function because it is possible that different neural substrates mediate similar functional abilities at different age ranges due to dynamic neuronal morphology (Moor, Op de Macks, Güroğlu, Van der Molen & Crone, 2011).

Gender accounted for differences on one executive function scale, description score for perceptual sorts, where males performed better than females, and two indices of the MASC (Dziobek et al., 2006). However, gender accounted for relatively few group differences and was not driving group differences on executive function measures. Other research supports this assumption showing no gender differences in behavioural results on Letter Fluency (Harrison, Buxton, Husain & Wise, 2000), planning assessed with the Tower of London (Asato, Sweeney & Luna, 2006; Boghi et al., 2006; Luciana, Collins, Olson & Schissel, 2009) and inhibition (Magar, Phillips & Hosie, 2010).

Females attained a higher total score on the MASC and made fewer errors involving over-attribution of mental state content compared to males, which may be explained as gender differences in interpreting expression intensity. Previous research has shown that females were more accurate than males on an emotion recognition task; however the gender difference was only apparent with subtle expressions at 50% intensity compared to 100% intensity (Hoffmann, Kessler, Eppel, Rukavina & Traue, 2010). Thus, gender differences may be evident on the MASC because this task approximates real life social situations where emotions are portrayed at low to mid intensity (Motley & Camden, 1988). Females also rated themselves significantly higher than males on the Empathic Concern scale of the Interpersonal Reactivity Index, assessing sympathetic feelings towards others, in line with other research (Davis, 1983; Derntl et al., 2010; Krämer, Mohammadi, Doñamayor, Samii & Münte, 2010) possibly due to participants conforming to gender stereotypes (Derntl et al., 2010).

To conclude, present data provide norms for the typical trajectory of social cognition and executive functions in late adolescence/early adulthood and indirectly inform understanding of abnormal functioning in neuropathological groups. It is important to understand the normal trajectory of executive and social cognitive function in typically developing adolescents because this has implications for assessment and rehabilitation of neuropathological groups at these age ranges (Reynolds & Horton, 2008). Future research could consider the implications that non-linear development of letter fluency and concept formation executive functions have on academic achievement. A dip in academic performance has been reported at Key Stage 3 (11 to 13 years) and attributed to commencing secondary school (Whitby, Lord, O'Donnell & Grayson, 2006), but might also reflect non-linear functional development given present findings. Notably, although 18 years of age is considered a cultural and legislative marker of adulthood, 18 year olds in the present study performed more poorly on strategy generation and concept formation compared to their younger counterparts. This finding has potentially broad ramifications and might indicate the executive functions seen after neuropathology at 18 years might not occur as a result of injury but rather as a natural consequence of neuronal re-organisation. It is plausible that specific functions might be temporarily diminished or abolished 'going offline' during periods of steep maturational change partially explaining increased risk-taking, poorer behavioural inhibition and reduced impulse control in adolescence compared to earlier childhood (excluding infancy) and later adulthood.

To conclude, converging evidence suggests that adolescence represents an important phase of neural reorganization with associated behavioural changes paralleled by changing friendship groups and living arrangements. Therefore, present findings likely reflect the complex interplay between maturational, social and environmental changes that take place in late adolescence and early adulthood and provide evidence of linear social cognitive and non-linear executive function development in late adolescence.

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Table 1.

Participant demographic data

Measure	17 year olds *(n = 31)*	18 year olds (*n* = 31)	19 year olds (*n* = 36)
Verbal IQ	105.35 (7.51)	103.55 (11.78)	102.69 (9.36)
Performance IQ*	105.39 (10.62)	99.97 (9.39)	104.83 (7.93)
Full Scale IQ	106.03 (7.43)	102.13 (10.98)	104.33 (7.65)
Pubertal development*	3.57 (0.32)	3.77 (0.27)	3.84 (0.21)
Ever used cannabis	45%	26%	22%
Ever used ecstasy	10%	7%	6%
Ever used alcohol	77%	94%	89%
PANAS Positive Affect	30.00 (4.32)	30.87 (7.43)	32.56 (4.75)
PANAS Negative Affect*	14.68 (5.22)	13.87 (3.31)	11.86 (2.38)
HADS – Anxiety*	8.38 (2.90)	8.38 (3.38)	6.65 (2.80)
HADS - Depression	3.14 (1.64)	2.58 (3.13)	3.21 (2.41)
Mental illness	3% Depression 6% Obsessive compulsive disorder	3% Depression 3% Depression and Attention Deficit Hyperactivity Disorder 6% Obsessive Compulsive Disorder	2% Depression 2% Obsessive Compulsive Disorder

* p<0.05

Table 2.

Means and standard deviations for 17, 18 and 19 year old age groups on executive function tasks (Hayling & Brixton Tests, D-KEFS Letter Fluency, Card Sorting and Tower Task)

	17 year olds *(n = 31)*	18 year olds (*n* = 31)	19 year olds (*n* = 36)
Measures of response inhibition and rule detection			
Hayling scaled	5.97 (1.25)	5.74 (1.37)	5.22 (1.76)
Brixton raw errors	12.10 (6.76)	11.94 (4.56)	12.47 (5.50)
Measure of strategy generation			
Letter fluency *	39.35 (7.56)	34.00 (8.60)	36.06 (7.36)
Measures of concept formation			
Free sorts correct *	12.00 (1.97)	10.74 (1.53)	10.83 (1.98)
Free sort description score *	45.23 (7.66)	39.97 (7.78)	41.75 (7.34)
Sort recognition description score *	48.97 (6.44)	44.42 (7.89)	45.08 (6.81)
Verbal sorts description score	31.84 (7.96)	28.71 (7.10)	30.17 (8.11)
Perceptual sorts description score *	62.35 (8.92)	56.94 (9.99)	56.31 (8.17)
Measures of planning			
Number of Tower items completed	8.42 (0.85)	8.13 (0.96)	8.33 (0.72)
Tower achievement score	18.26 (2.85)	18.32 (2.70)	17.64 (2.95)
Mean first move time	3.08 (1.10)	3.89 (1.83)	3.96 (1.84)
Time per move	2.60 (0.62)	2.80 (0.78)	2.74 (0.52)
Move accuracy	1.66 (0.44)	1.57 (0.46)	1.65 (0.37)

* $p<0.05$

Table 3.

Hierarchical regression analyses with age, living changes and HADS Anxiety as predictor variables and D-KEFS Letter Fluency score as the dependent variable.

	ΔR^2	ΔF	df	β
Step 1: Age	0.04*	3.31	1,87	0.19*
Step 2: Age	0.01	0.52	1,86	0.15
Living change				0.09
Step 3: Age	0.01	0.47	1,85	0.16
Living				0.10
Anxiety				0.08

* $p<0.05$ one tailed

Table 4.

Hierarchical regression analyses with age, living changes and HADS Anxiety as predictor variables and number of correct free sorts on the D-KEFS Sorting Test as the dependent variable.

	ΔR^2	ΔF	df	β
Step 1: Age	0.06	5.68**	1,87	0.25**
Step 2: Age	<0.01	0.67	1,86	0.20*
Living change				0.10
Step 3: Age	<0.01	0.53	1,85	0.19
Living				0.08
Anxiety				0.08

* $p<0.05$ one tailed
** $p<0.01$ one tailed

Table 5.

Means and standard deviations for 17, 18 and 19 year olds on social cognition tasks (Reading the Mind in the Eyes, Reading the Mind in the Voices, Movie for the Assessment of Social Cognition and Interpersonal Reactivity Index) and existing normative adult data.

	17 year olds *(n = 31)*	18 year olds (*n* = 31)	19 year olds (*n* = 36)	Existing adult data	
Static visual stimuli					
Eyes	27.26 (4.83)	27.61 (3.55)	28.23 (3.26)▲	25.1 (3.8)	*M* = 31.8 years
				Kirchner, Hatri, Heekeren & Dziobek (2011)	
Auditory stimuli					
Voices	17.06 (2.25)	16.97 (2.66)	16.86 (2.26)	18.77 (2.41)	*M* = 24.3 years ▲
				Golan, Baron-Cohen, Hill & Rutherford (2007)	
Dynamic visual and auditory stimuli with social interaction					
MASC correct	35.48 (3.79)	35.19 (3.25)	35.83(3.32)▲	33.34 (5.26)	*M* = 33.2 years
MASC excessive mental state inference errors	5.48 (2.78)	6.16 (2.25)	5.19 (2.73)	Ritter et al. (2011)	
MASC insufficient mental state inference errors	2.48 (1.81)	2.39 (1.26)	2.69 (1.51)		
MASC no ToM errors	1.55 (0.93)	1.26 (1.00)	1.28 (1.06)		
Self report empathy					
IRI Fantasy	18.35 (5.35)▲	16.65 (6.06)	17.86 (4.37)	16.30 (5.40)	
IRI perspective	17.03 (3.85)	16.90 (4.00)	17.03 (4.04)	20.40 (4.20)▲	
IRI empathic	21.29 (3.45)	20.26 (3.66)	20.60 (3.08)	21.60 (4.30)	
IRI personal distress	12.61 (4.67)	14.52 (5.28)	14.06 (4.21)	10.10 (3.90) ▲	
				Hassenstab et al. (2007)	

▲ best performance on tasks . All p>0.05 for 17, 18 and 19 year old differences

Table 6. Comparison between late adolescent data (17, 18 and 19 year olds) and existing normative adult data on executive function tasks. ▲ best performance on task

	17 year olds (*n = 31)*	18 year olds (*n* = 31)	19 year olds (*n* = 36)	Existing adult data
Measures of response inhibition and rule detection				
Hayling scaled	5.97 (1.25) ▲	5.74 (1.37)	5.22 (1.76)	5.60 (0.76) *M* =28.2 years Henry, Mazur & Rendell (2009)
Brixton raw errors	12.10 (6.76)	11.94 (4.56)	12.47 (5.50)	10.7 (35.00) ▲ *M* = 22.8 years Andrés & Van der Linden (2000)
Measure of Letter Fluency				
Letter fluency	39.35 (7.56)	34.00 (8.60)	36.06 (7.36)	48.3 (17.57) ▲ *M* =28.2 years Henry, Mazur & Rendell (2009)
Measures of concept formation				
Free sorts correct	75.00%	67.13%	67.69%	80.22% *M* = 22 years ▲
Free sort description score	70.67% ▲	62.45%	65.23%	71.89% ▲
Sort recognition description score	76.52% ▲	69.41%	70.44%	76.72% ▲ Greve et al. (1995)
Measures of planning				
Number of Tower items completed	8.42 (0.85)	8.13 (0.96)	8.33 (0.72)	
Tower achievement score	18.26 (2.85)	18.32 ▲ (2.70)	17.64 (2.95)	17.88 (3.83) *M* = 23.03 years
Mean first move time	3.08 (1.10)▲	3.89 (1.83)	3.96 (1.84)	34.21 (27.81)
Time per move	2.60 (0.62)▲	2.80 (0.78)	2.74 (0.52)	3.30 (1.08)
Move accuracy	1.66 (0.44)	1.57 (0.46)▲	1.65 (0.37)	1.68 (0.37) Larochette, Benn & Harrison (2009)

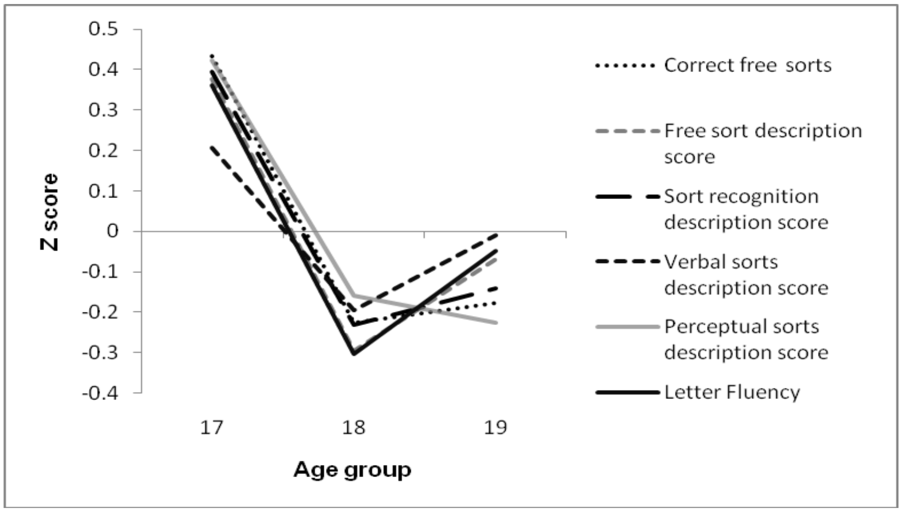

Figure 1. Mean Z Scores for 17, 18 and 19 year old age groups on the D-KEFS Sorting Test measure of concept formation, and the D-KEFS Letter Fluency Test measure of response generation