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When Do We Become Adults? Review of Theory, Research and Recent Advances from an Interdisciplinary Perspective

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Abstract

Major developmental psychology theories, such as psychoanalytic, behavioural or cognitive, have tried to explain how people grow and change over the course of a lifetime. These theories have mainly focused on the stages of development early in life - from infancy to adolescence - leaving the impression that after adolescence no significant leaps in development occur. However, a large body of evidence that has emerged recently revealed that becoming an adult is much more complicated and temporally extended than previously believed. The aim of this paper was to use an interdisciplinary approach to tap into the issue of transition to adulthood by integrating recent brain and cognitive maturational findings from neuroscience and cognitive psychology while considering traditional and legal markers of adulthood. We first discuss some of the questions related to definitions of the period of adulthood through societal and legal frameworks. Next, we examine some of the prevailing views on protracted structural and functional brain maturation and its impact on cognitive development, emphasizing the need and the potential value of investigating how these changes may influence important life choices during early young adulthood that have long-lasting consequences. Finally, based on evidence from existing research, we highlight the importance of deeper appreciation and integration of findings from different research disciplines in order to better understand strengths and vulnerabilities of young adults.

Keywords: young adults, achieving adulthood, protracted brain maturation, cognitive development, interdisciplinary perspective, adolescents

Introduction

All major developmental psychology theories have tried to explain how people grow and change over the course of a lifetime. These theories have different implications for how their findings may be applied to our everyday lives. Psychoanalytic theories, mostly influenced by the work of Sigmund Freud, proposed that development occurs through a series of psychosexual stages, emphasizing the importance of the unconscious mind and childhood experiences. Erik Erikson

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formed an eight-stage theory of psychosocial development describing how one grows and changes through the entire lifespan by overcoming various conflicts at each stage while building upon previous experiences. Watson, Pavlov, Skinner and Bandura, main representatives of learning theories, focused on how the environment impacts behaviour through classical conditioning, operant conditioning and social learning. On the other hand, Piaget in his theory of cognitive development focused on the development of mental processes, skills, and abilities which are in accordance with ongoing biological changes.

Most of these theories have mainly focused on the stages of development early in life - from infancy to adolescence - leaving the impression that after adolescence no significant leaps in development occur. However, a large and relatively new body of evidence that has emerged recently revealed that becoming an adult is much more complicated and temporally extended than previously believed. It seems that the transition from adolescence to adulthood is not just marked by changes in social markers or legal boundaries, but also by dramatic changes in brain structure and function, and consequently, in cognitive skills.

One of the reasons that developmental theories are not able to encompass the full extent of the development is that despite their mutual interest, each discipline (sociology, biology, psychology) has been studied in isolation. The aim of this review was to use an interdisciplinary approach to tap into the issue of transition to adulthood by integrating recent brain and cognitive maturational findings from neuroscience and cognitive psychology while considering traditional and legal markers of adulthood. In this review, we show that even though many social studies reveal that in most modern societies the period of transitioning to adulthood is more prolonged than ever before, and neuroimaging studies support the continuation of structural brain development after adolescence, much less is known about how these changes relate to maturation of cognitive functions at this age, and hence the corresponding developmental models are still lacking.

The focus of the present article is to review relevant research on protracted social, cognitive and brain development across adolescence and early young adulthood in order to add to the current discussion regarding the transition to adulthood, as well as to offer a few suggestions for how future research in this area might be utilized to increase our understanding of never-ending question - when do we become adults? We first discuss some of the questions related to definitions of the period of adulthood through societal and legal frameworks. It seems that the period of transitioning to adulthood has become much more complex and diversified than it was the case 50 or 60 years ago. Next, we examine some of the prevailing views on protracted structural and functional brain maturation and its impact on cognitive development. Studies using various neuroimaging methods have shown that even though important aspects of brain circuitry are in place in adolescence and the performance is close to adult level, there are still inflexibilities in the brain networks that limit the efficient and flexible use of cognitive control.

The new findings which confirm that the changes in brain structure, cognitive skills and related performance continue into early young adulthood challenge current developmental models, emphasizing the need for a new theoretical framework which will incorporate these findings. Might this be a life stage that deserves more attention from various research disciplines, rather than a new cultural trend that is occurring depending on social backgrounds and likely economic prospects? Based on the evidence from existing research, we highlight the importance of deeper appreciation and integration of findings from different disciplines in order to recognize strengths and vulnerabilities of young adults. These new findings may provide a better description of the complexity of transition from adolescence to adulthood.

Social studies are mostly focused on explaining the reasons behind the lengthened period between the onset of puberty and the fulfilling of cultural expectations around adult roles, like financial independence and family formation.

Social Markers of Transition to Adulthood

Young adulthood is broadly defined as the age between 18 and 40 years. In 1950s and 1960s social scientists from numerous fields showed that most demographic events that mark the entrance into adulthood occurred early during this life stage, within a relatively limited time-span and usually in a sequential order – people left home and entered the workforce, got married and became parents a few years later (Hendry & Kloep, 2007). Most young men and women married in their late teens or very early twenties and had their first child about a year later. Until marriage, they lived with their parents and only 25% (almost all men) attained any higher education (Arnett, 2000; Billari & Liefbroer, 2010). These key transitions were commonly considered to be the criteria for reaching adulthood. However, during the last two decades, it has been increasingly argued that the process of transition to adulthood has become more complex, diversified, and prolonged than ever before (Jensen & Arnett, 2012). Nowadays young people explore many more options while searching for a suitable career, partner, or housing possibilities. They stay in school longer, marry later, and have their first child later than in the past. For example, Schoon and Lyons-Amosba (2016) identified five distinct pathways to employment in UK: (1) early work orientation involving continuous employment from the age of 16, (2) transition to employment around the age of 19 after some education, (3) persistent unemployment at the age of 19 as a result of constant transitions between being employed or in school, (4) inactivity due to illness or taking care of family home, and (5) extended education followed by transition to work up to the age of 23.

The pathways into adulthood have certainly become more flexible, variable, and less uniform. Some move more slowly through these processes and others make relatively fast transitions to independent adult life. In a study among Finnish university students during an 18-year follow up, researchers have identified six

pathways into adulthood related to family and work roles: (1) career and family pathway in which all key life transitions to adulthood occurred in a "normative" or expected order, (2) slow starters in which both career and family transitions were postponed, (3) singles with slow career in which individuals had difficulties in forming and committing to a partnership and were slow in starting their work career, (4) fast starters characterized by fast transition in all of the key life domains, (5) career and unsteady partnerships where individuals moved early to employment and entered partnership during university studies but then experienced several partnerships and repeated breakups, and (6) fast partnership and late parenthood pathway with early formed partnership that remained steady, but transitioned to parenthood relatively late (Salmela-Aro, Kiuru, Nurmi, & Eerola, 2011). Billari and Liefbroer (2010) showed that throughout Europe many demographic events occur rather late in young adulthood, the time span between the first and the last transition is relatively long, and many of these events (e.g., completing schooling, obtaining a full-time job, establishing an independent household, forming a family) occur and often reoccur during this time. Similar patterns have been found across USA (Arnett & Tanner, 2006) as well as in other counties around the world (Swanson, 2016).

Today traditional social markers do not stand for attaining adulthood anymore. As one of the main reasons behind this prolongation of the entrance into adulthood researchers point out changes in labour market and the social structure in industrialized cultures (Schwartz, Donnellan, Ravert, Luyckx, & Zamboanga, 2010). Studies show a global rise in the age of first marriage across continents, coupled with childbirth statistics, and significantly fewer percentages of women marrying before the age 20 (Arroyo, Payne, Brown, & Manning, 2013; Curtis, 2015). In addition, formal education has been increasing, with narrowing discrepancies between educational opportunities for women and men (Curtis, 2015). The combination of delayed marriage and childbirth with prolonged education fosters an international trend towards prolongation of the time an individual needs in order to become an adult according to societal norms and expectations. This set of interrelated demographic changes, and the psychological transformations accompanying them, has led an increasing number of scholars to conclude that this period of transition to adulthood should be described as a distinct phase in the life course between adolescence and adulthood (Jensen & Arnett, 2012; Schwartz et al., 2010; Swanson, 2016).

The first scholar who proposed a new period of development from late adolescence through the early twenties was Arnett (2000), who focused on ages 18 - 25. He pointed out that this period is neither adolescence nor young adulthood, and referred to it as the "emerging adulthood". He describes "emerging adulthood" as a period of social instability, change and exploration. According to Arnett's theory, "emerging adulthood" is: a) the age of identity explorations, including frequent changes in love partners, educational and occupational selection, b) the age of instability, because it adds an element of stress and anxiety, c) the self-focused age,

because it is the least structured time of life and the least bound by obligations to others, d) the age of feeling in-between adolescence and adulthood, because many of young adults at this age do not feel like adolescents any more but do not yet feel as adults either, e) the age of possibilities as a time of high hopes and great expectations, with a window of opportunity for people to make dramatic changes in their lives (Arnett, 2000; Schwartz, Cote, & Arnett, 2005; Tanner, Arnett, & Leis, 2009). Many developmental theorists presume that a prolonged transition into adulthood has become a cultural imperative in industrialized societies (Arnett, 2003; Chung et al., 2014; Jensen & Arnett, 2012; Settersten, Ottusch, & Schneider, 2015; Tanner et al., 2009). Hence, the number of studies on emerging adulthood has significantly grown in the last 15 years. Even though the emerging adulthood research has strong roots in the adolescent field of study, it is now taking on the status of being a legitimate filed of its own (Swanson, 2016).

However, there is a considerable variability between industrialized and developing countries. For example, while the percentage of American young people entering higher education has risen by about 50% in the last 60-70 years, thus delaying full-time employment, marriage and parenthood until at least mid-20s (Arnett & Tanner, 2006), cultures with lower socioeconomic status include more adolescents in the adult family roles and labour market (Curtis, 2015). This restriction of emerging adulthood to industrialized societies is one of the major arguments against Arnett's theory. In this context, Alice Schlegel (1995), after reviewing information on adolescence in 186 traditional non-Western cultures, concluded that period between adolescence and adulthood existed in only 20% of the cultures, unlike adolescence which is virtually universal. Hendry and Kloep (2007) point out on several limitations of Arnett's theory of emerging adulthood. The transition from adolescence to adulthood is not as smooth as Arnett proposes - it changes depending on the domain and can be reversible. Young people might reach adult status early in some aspects and later in others, but some may never achieve adult status according to their own perceptions or social markers. Thereafter, they can find themselves in circumstances which would make them regress, e.g., returning to their parent's home after losing a job (Hendry & Kloep, 2007). In the USA, the vast majority of the full-time workers are aged between 25 and 64 years (Curtis, 2015), and, according to the Affordable Care Act, youth through the 25th year are allowed to be included as dependents on their parent's health care insurance (The Centre for Consumer Information & Insurance Oversight, 2015). Considering their economic self-sufficiency and overall social costs associated with the prolonged period of moving into adulthood, some social analysts and policy-makers argue that this will certainly place large financial (and emotional) burden on middle-aged parents, having to support their "emerging" children at the same time as having to care for their ageing parents. Also, a large number of young adults not participating in the labour market in their first 30 years of life could have a great cost on post-industrial societies (Hendry & Kloep, 2007).

There is no doubt that managing everyday lives during young adulthood becomes more complex than during adolescence. An individual at this age can be deemed criminally responsible, is able to own firearms or purchase alcohol, drive a car, vote, or join the armed forces. There is a great variability in how different aspects of the law define the age of majority in various countries.

Defining Adulthood through Legal Boundaries

Determining exactly when the longest period of human development – the adult life – begins is unclear even when looking through legal definitions. The age of majority is the threshold of adulthood as recognized by the law. It is the age when an individual, through the eyes of the law, assumes control and responsibility for his person, actions and decisions. It does not depend on the mental or physical maturity of an individual, and it is not always set to 18, but varies between 15 and 21 (Curtis, 2015). The youngest age at which one can be held responsible and subjected to punishment for offences considered by criminal code as less serious is specific to each country, but is between 10 (e.g., Australia) and 12 (e.g., Belgium, Canada). For more serious offences, the lowest age limit for criminal liability varies between the ages 14 to 16 (Steinberg, 2013).

The legal age requirement for handgun possession is 18 in most of the USA, but states have set their own minimum age laws, and in some a 14-year old can legally own rifles or shotguns (Smartgunlaws.org, 2014). In most European countries 18 is also the minimum age, except for hunting and target shooting, when less than 18 is acceptable under adult guidance, with no minimum age limit. In most countries around the world the military draft starts at 18, however, with parental consent, the possibility of enlisting varies between 14 and 17 (Central Intelligence Agency, 2016). The marriage age of consent is set to 18 in most countries, but with parental and/or the consent of a judge, the lowest age limit varies from 13 to 18 (Robertson, 2016). Driving age minimum varies from 14 to 18, while the minimum legal age for purchase of alcohol ranges from 16 to 20 in most countries around the world, but is set to 21 in the USA (Kadiri, 2014).

Risk Taking and Reckless Behaviours in Early Adulthood

Excessive alcohol consumption often escalates during the early adult years. More than 30% of young adults between the ages of 18 and 24 report binge drinking (consuming several alcoholic drinks within two hours, generally five for men and four for women) at least once in two weeks in the USA (Willoughby, Good, Adachi, Hamza, & Tavernier, 2014). 24% of Australians in the same age group report binge drinking at least once a month (Courtney & Polich, 2009), while in Europe 22% of those aged 15-24 years report binge drinking at least once a week (Hanewinkel et al., 2012). Actually, the highest rates of substance and alcohol use disorders are found between the ages 18 and 25 (Carter, Brandon, & Goldman, 2010).

Unlike most other periods of life, the leading causes of death in late adolescence and early young adulthood (between 15 and 24 years of age) are road traffic accidents, homicide and suicide (Sethi, Racioppi, & Bertollini, 2007). Even though adolescence is commonly referred to as "the rules are made to be broken" age, the prevalence of several types of risk-taking behaviours, like risky driving at high speed or while intoxicated, actually peaks during the early 20s (Steinberg, 2008). Shulman and Cauffman (2014) investigated risk-taking in 282 participants aged 10-30 years. When they were asked to make quick, intuitive assessment of risk behaviour, researchers found that the peak age for the most favourable attitudes toward risk-taking is between 20 and 21.

Taken all together, social, economic, and demographic changes over the past 50-60 years have resulted in dramatic changes in what occurs during the late teens and through the twenties for most young people in industrialized societies, making it harder to determine when adulthood begins. This is unclear even when looking through legal definitions of adulthood, mainly due to a great variability in how different aspects of the law across countries define when we become adults.

Becoming an "adult" involves enormous changes in roles and responsibilities, which require greater use of effortful control and sophisticated cognitive skills in order to modify emotions and behaviour, make appropriate decisions, consider consequences, prioritize, focus on important details and shift between tasks and activities. Researchers agree that the inclination to risk-taking behaviour (e.g., drunk driving, substance abuse) is strongly related to slow maturation of cognitive control system which regulates these impulses (Luna, Padmanabhan, & O'Hearn, 2010). The optimal use of these abilities evolves gradually and depends on brain-based control mechanisms. While brain-based control mechanisms are still developing, it is more likely to act impulsively when confronted with stressful or emotional decisions. Even though cognitive challenges in young adulthood are generally very high, if we review the scientific literature from 10-15 years ago we can find virtually nothing about the typical development of brain structures that underpin these complex processes after childhood.

What's Brain Got to Do with It?

During the 1980s and 1990s, researchers published extensive data on synapse formation in the cerebral cortex of the rhesus monkey (Bourgeois, Goldman-Rakic, & Rakic, 1994; Rakic, Bourgeois, & Goldman-Rakic, 1994). Their data revealed several similarities between human and monkey brains: a phase of rapid synaptogenesis followed by a plateau phase of above adult levels of synaptic density in early infancy, and consequently elimination during childhood and adolescence. However, the postnatal refinement of cortical microstructure progresses along a more protracted timetable in humans relative to other primates. Whereas other primates are born with brains that already weigh about 70% of adult mass, in humans only

about 25% of adult mass is achieved at birth, while a large proportion of the brain growth occurs postnatally, allowing different social and environmental factors to impact the formation of neural network (Bianchi et al., 2013). Overall, in human cerebral cortex peak synapse density occurs in mid-childhood around the age 5, while pruning of synapses extends into the third decade of life, especially in prefrontal regions. Synaptic density peaks earlier in phylogenetically older brain areas (i.e., at 3 months in auditory cortex) compared to newer cortical areas (i.e., at 15 months in the middle frontal gyrus), and dendritic growth occurs in parallel with synaptogenesis (Huttenlocher & Dabholkar, 1997; Petanjek et al., 2011).

The use of magnetic resonance imaging (MRI) opened a whole new era, allowing researchers to non-invasively document large-scale processes of brain development, provide insights into the sequence of these developmental processes in longitudinal experiments, and document how they occur in living subjects. Many cross-sectional and several longitudinal studies using MRI have demonstrated that healthy human brain development occurs through childhood and adolescence. These life periods are marked by significant changes due to undergoing maturation of behavioural, emotional, hormonal, and cognitive processes. However, brain maturation does not end with adolescence, but rather continues into young adulthood.

The most consistent findings from research using structural MRI in typically developing human brain show that the cerebral volume does not change significantly after the age 9-10 (Brown & Jernigan, 2012). However, grey matter volume follows an inverted U-shaped developmental trajectory, where the total volume in the brain increases before puberty and decreases after puberty (Gogtay & Thompson, 2010). This is consistent with post-mortem observations of increased synaptic pruning (elimination of unused neuronal connections) during adolescence and early young adulthood. Grey matter density on MRI is an indirect measure of glial cells, vasculatures, and neurons with dendritic and synaptic processes. Grey matter loss is considered an index of the time-course of maturation of a region (Sowell et al., 2003). Neuroanatomical studies have shown that regions subserving primary functions, such as motor and sensory systems, are first to mature. Temporal and parietal association lobes, responsible for basic language skills and spatial attention, mature next. Finally, the prefrontal and lateral temporal lobes, which integrate primary sensorimotor processes and are involved in complex cognitive behaviours, such as memory, planning or foresight of consequences, seem to mature last (Blakemore, 2012; Crone & Steinbeis, 2017).

Myelination, the thickening of the myelin sheath surrounding axons, is one of the most prolonged developmental processes in the human brain. Myelin acts as an insulator and massively increases the speed of transmission of electrical impulses from neuron to neuron, and consequently, from one brain area to another (Paus, 2010). In contrast to grey matter, white matter's volume increases more or less linearly throughout the first three decades of life, showing more rapid changes at early ages, and slowing or levelling off during young adulthood (Tamnes et al.,

2011). White matter density and myelination changes are not region-specific as are in grey matter, but rather wide-spread across the brain. Studies using diffusion tensor imaging (DTI, a brain imaging technique which provides unique insights into brain network connectivity) have shown that maturation of commissural fibres (which connect one cerebral hemisphere to the other) and projection fibres (which connect cerebrum with other parts of brain and/or spinal cord) occurs earliest; association fibres (which connect regions of the cortex within the same hemisphere) continue maturation at later ages, while frontal-temporal connections display the most prolonged development (Lebel & Beaulieu, 2011).

In summary, cellular and structural studies have demonstrated protracted postnatal brain development, with considerable changes in cerebral cortical and subcortical structures, as well as changes in grey matter and white matter area, thickness and connectivity. As a number of researchers point out, it seems that "the U.S. rental car companies have it right": the brain is not fully mature at the age of 16, when young people are allowed to drive, or 18 when they are allowed to vote, or 21 when they are allowed to drink, but closer to 25, when they are allowed to rent a car. The question then arises: what are the cognitive and behavioural implications of this refined neuroanatomical reorganization that continues into young adulthood?

The Interplay between Brain Maturation and Cognitive Development

It is well known that the ability to use cognitive control over behaviour and thoughts improves during childhood and adolescence. The concept of cognitive control (also called executive control or executive functions) refers to a set of interdependent cognitive abilities that are needed to monitor and change behaviour flexibly and in accord with the internal goals and situational demands (Luna et al., 2010). It is an umbrella term and its subcomponents are commonly evaluated with tasks that reflect constituent functions such as: holding in mind and carrying out goal-directed plans, inhibiting unwanted or inappropriate behaviour, shifting the mindset and adapting to diverse situations. Primate (Bianchi et al., 2013; Rakic et al., 1994), human lesion (Barbey et al., 2012), and neuroimaging (Crone & Steinbeis, 2017) studies suggest that such skills rely heavily on the prefrontal lobe, but the whole brain integrity is necessary for efficient cognitive control functioning. It seems that brain regions that are responsible for these cognitive skills are already "online" early in development. Nonetheless, even though adolescents and early young adults can perform complex voluntary goal-directed behaviour, their decisions are often inconsistent and suboptimal (Luna et al., 2010). Studies report changes in the location of activation and the amount of activation in the neural response underlying cognitive control functions from childhood to adulthood.

Response Inhibition and Performance Monitoring

The hypothesis that the development of the prefrontal cortex is closely tied to the development of cognitive control has been suggested by many theoretical models ever since it was found that patients with damage to this brain region show deficits in cognitive control (Stuss & Levine, 2002). More recent models have suggested that development of various sub-processes of cognitive control is related to the maturation of various sub-regions of the prefrontal cortex (PFC) (Crone & Steinbeis, 2017). The key components of cognitive control that are thought to be crucial for regulation of behaviour are response inhibition and performance monitoring. The former enables individuals to actively suppress, interrupt or delay an action, while the latter refers to the ability to monitor performance and detect errors (Luna et al., 2010). Both of these cognitive control functions improve through childhood, adolescence and early young adulthood, and are supported by the primarily prefrontal cognitive control network, including anterior cingulate cortex (ACC). Functional MRI studies show that improvements in response inhibition and performance monitoring are accompanied by both increased brain activation in inferior frontal cortex in adults (ages 20-42 and 23-25) compared to adolescents (ages 10-17 and 18-19), increased recruitment of ACC and PFC in adults (age ranges 18-47) compared to adolescents (ages 10-17), and decreased activity in medial frontal cortex in adults (ages 25-30) compared to adolescents (ages 9-19) (Knežević, Veroude, Jolles, & Krabbendam, 2016; Rubia et al., 2013). In addition, young adults between the ages 19 and 25 show impulsive behavioural tendencies (premature responses, lower accuracy, shorter reaction times) compared to those aged 28-42 (Knežević & Marinković, 2017), suggesting that response inhibition and performance monitoring do not fully develop before roughly the age of 25.

The ability to monitor, evaluate, and adjust behaviour according to changing environmental and social demands improves rapidly during development, especially after receiving feedback that signals the need to adapt current behaviour. For example, Crone, Zanolie, Van Leijenhorst, Westenberg, and Rombouts (2008) measured developmental differences in neural activity associated with different aspects of feedback processing in three age groups: early adolescents (8-11 years), mid-adolescents (14-15 years), and young adults (18-25 years). They found that early adolescents activated ACC and pre-supplementary motor area (pre-SMA) for all types of negative feedback, whereas both mid-adolescents and young adults activated this region specifically after unexpected negative feedback that signalled the need to adjust current behaviour, indicating changes in the pattern of brain activation related to negative feedback processing between early- and mid-adolescence. Dorsolateral PFC following negative feedback showed even a more protracted development with continued increases between mid-adolescence and young adulthood. In addition, the number of errors was higher in mid-adolescents compared to young adults (Crone et al., 2008).

Working Memory

The ability to temporarily maintain information available for processing is known as working memory, another important subcomponent of cognitive control. Similar to response inhibition and performance monitoring, working memory improves through childhood, adolescence and young adulthood (Luna et al., 2010). Miyake et al. (2000) proposed the unity and diversity model after investigating whether latent variables, such as mental set shifting, information updating and monitoring, and inhibition of prepotent responses, predicted performance of 137 college students on more complex cognitive control tasks derived from a battery of psychological tasks: the Wisconsin Card Sorting Test, Tower of Hanoi, random number generation, operation span, and dual tasking. They found evidence that the development of working memory (updating and monitoring) contributed to performance on Wisconsin Card Sorting Test and the development of interference control contributed to performance on the Tower of Hanoi (Miyake et al., 2000). Developmental functional MRI studies show consistent patterns of working memory development in association with increases in dorsolateral PFC activity across studies throughout adolescence and early adulthood (Crone & Steinbeis, 2017). More specifically, working memory is supported by a widely-distributed brain network, including ventrolateral and dorsolateral PFC, as well as posterior parietal cortex. While adolescents show more diffused frontal network activation (including dorsolateral PFC, inferior frontal gyrus, middle temporal gyrus, ACC, posterior parietal cortex, anterior insula), adults show most localized brain activity (dorsolateral PFC, ventromedial PFC and supramarginal gyrus) coupled with performance enhancement (Crone & Steinbeis, 2017; Geier, Garver, Terwilliger, & Luna, 2009). This age-related change in working memory has been explained as an increase in the ability to process information, meaning that working memory's capacity functions more efficiently with advancing age (Crone & Ridderinkhof, 2011).

There are other cognitive control functions which also develop relatively late, although research on their developmental trajectories is still missing. For example, temporal foresight which is crucial for planning and decision-making or even simpler cognitive functions such as selective attention are thought to be progressively refined during adolescence and early adulthood (Rubia, 2013). However, most studies have concentrated on early childhood, whereas later developmental periods have been somewhat neglected.

Social Decision-Making

Becoming an adult is not only about developing skills in order to change behaviour and thoughts in accordance with our own goals, but also to be able to understand and respond to changes in a social environment and adapt to novel situations. The ability to understand others' mental states, emotions and actions is

known as the theory of mind. The theory of mind becomes increasingly important during adolescence and young adulthood, when the focus is shifted from immediate family towards peers, friends, and romantic partners. While basic theory of mind skills (like understanding that someone else can hold a belief that is different from our own) are present in childhood, more complex skills like perspective taking or metacognition mainly develop across adolescence and young adulthood (Blakemore, 2012; Crone & Dahl, 2012; Crone & Steinbeis, 2017; Pfeifer & Blakemore, 2012). A large number of neuroimaging studies have identified several key regions responsible for mentalizing: posterior superior temporal sulcus at the temporoparietal junction, medial PFC and superior temporal lobes (Pfeifer & Blakemore, 2012). This so-called "social brain network" undergoes structural and functional changes during development. While adolescents show more activation in medial PFC than adults, adults show more activation in temporoparietal junction than adolescents during various theory of mind tasks. The main change that is found in adolescent behaviour along with structural and functional changes in the brain is the shift from self-oriented behaviour to pro-social behaviour, i.e. behaviour oriented toward others. This kind of behaviour is particularly important for successful functioning in various social situations (Blakemore, 2012; Shulman & Cauffman, 2014).

Taken together, research that made use of cognitive control paradigms combined with neuroimaging provided evidence that brain regions that are typically associated with cognitive control (such as the dorsal medial PFC and lateral PFC) show developmental changes throughout adolescence and early young adulthood, in line with changes in the efficiency of exerting cognitive control over behaviour. This suggests that the maturation of the prefrontal cortex is closely tied to the development of cognitive control at this age. Even though important aspects of brain circuitry are in place in adolescence and the performance is approximating that of adults, there are still inflexibilities in the brain networks that limit efficient and flexible use of cognitive control. The transition to adulthood seems to include relying more on a broader network of brain regions which share processing (e.g., prefrontal and posterior regions), freeing up cognitive control regions for more complex processing. This transition is supported by structural changes in the brain (e.g., synaptic pruning, myelination) which seem to leave the remaining brain circuits better specialized and more efficient. The interplay of cognitive abilities and neuroanatomical restructuration can be explained in at least three ways: as maturational progress of additional brain areas, as a change in interaction between brain areas that were already active, or as a change in patterns of activation in different brain regions as a result of acquisition of new skills (Crone & Ridderinkhof, 2011; Luna et al., 2010).

Developmental Theories and Theoretical Frameworks

The findings that refinements in brain structure, cognitive skills and related performance continue through adolescence and into young adulthood challenge accepted views and current developmental models. Theoretical frameworks which

we could borrow from cognitive psychology in order to interpret these findings are quite limited since they mostly focus on early stages of human life. In an effort to merge findings from cognitive psychology and neuroscience, Crone and Ridderinkhof (2011) pointed to Jean Paget's theory, since his work has probably been the most influential on our thinking about brain and cognitive development. Despite his controversial theoretical postulations by which he underestimated children's cognitive abilities, it is possible to associate Piaget's ideas of stage development with sensitive periods of brain development. Piaget suggested that a child cannot reach a new stage before mastering the previous one. Research from neuroscience has shown that grey matter development in different brain regions is heterogeneous, and that grey matter changes in high-order brain region have to be completed before that region can contribute to specialised cognitive functions (Gogtay & Thompson, 2010). In addition, the maturation of white matter connections between and within specific regions is important for age-related changes in neural structure and improved cognitive performance (Tamnes et al., 2011). Several studies have tried to examine how changes in brain structure correlate with cognitive functioning during development, and their findings show that improvement in intellectual abilities from childhood to adolescence is related to maturation of both grey and white matter (Schnack et al., 2015; Shaw et al., 2006; Tamnes et al., 2011). It is unclear whether these changes occur suddenly or through gradual acquisition of experience and knowledge, but theories of brain maturation and cognitive development agree that changes in cognitive skills occur through an interplay between biological maturation and gaining experience (Crone & Ridderinkhof, 2011).

The dual system model of brain development (Steinberg, 2008) proposes that adolescents experience a temporal void between a relatively early maturing emotional system and slower maturing cognitive control system. The early maturing emotional system is thought to reflect increases in dopaminergic activity and subcortical brain structures, possibly linked to puberty, leading to increases in the need for seeking rewards and novelties. The slower maturing cognitive control network is thought to be governed by the prefrontal cortex responsible for inhibition, planning and decision making, which is not fully mature until at least mid-20s (Willoughby et al., 2014). Steinberg (2008) proposes that this asynchrony between the development of emotional and cognitive control systems leads to increased vulnerability for risk-taking, which peaks during mid-adolescence when the discrepancy between these two systems is the most accentuated. However, new insights about the protracted period of brain development, as described above, show that cognitive control systems are still maturing into young adulthood (Crone & Steinbeis, 2017). On the other hand, studies on the percentage of risk-taking in real-life settings through adolescence and young adulthood do not provide support for the dual system model, which proposes that the risk-taking would be the most prominent during mid-adolescence (Willoughby et al., 2014). One longitudinal study with 4412 adolescents aged 14-18 years found that the engagement in risk-taking behaviours (e.g., alcohol frequency and quantity, marijuana and hard drugs usage, and

delinquency) gradually increases across these ages (Hooshmand, Willoughby, & Good, 2012), in contrast to peaking in mid-adolescence as proposed by the dual system model. Moreover, research shows the highest level of risk-taking behaviour among university/college students (Willoughby et al., 2014).

Kloep and Hendry (2014) argue that developmental theories should put more emphasis on explaining how and why people change and move towards a more holistic approach. Some researchers propose that developmental studies should move away from stage theories which are bounded by age, and move towards theories which are based on a wide range of trajectories or possible pathways (Kloep & Hendry, 2014). While it is true that experience can cause developmental change, based on findings from neuroimaging and cognitive studies, it seems that this change cannot happen if biological foundations that underlie certain abilities are not in place. Experience impacts development in many different ways and can often change its course, but it does not cause developmental change per se. Rather, it is the interplay of biological maturation and experiences gained within dynamic environmental demands that result in developmental advancement. However, research linking changes in biological foundations (brain structure) to changes in actual human behaviour (cognitive functions) in various environmental surroundings is still very limited.

Moving Forward: Integrating Knowledge from Different Research Areas

Young adulthood is a life period of profound importance, a time of stunning achievements and internal and external changes that launch young people into adulthood. Becoming an "adult" involves enormous transformations in roles and responsibilities, which require adjustments in personal goals and motivations, such as developing priorities related to family, friends, romantic partners, community, education, career and religion. This is the age when young people make occupational and interpersonal choices and decisions which will affect the course of the rest of their life. One of the reasons that developmental theories are not able to encompass the full extent of the development is that despite the mutual interest - the well-being of young people - each research area has been studied in isolation. Even though classical traditional markers and events, such as getting a stable job or becoming a parent, seem to be much less important nowadays on the personal level, they still have a large impact on each individual and are important hallmarks of the adulthood in the society. Social studies show that the period of transitioning to adulthood is the least structured time of life, marked by instability and stress (Arnett & Tanner, 2006; Tanner et al., 2009). At the same time, neuroscience shows that adolescence and young adulthood is a particularly sensitive developmental period which can influence young adult's life course trajectory. One of the challenges for future studies is to better understand how individual differences in experiences with transitional events which mark the entrance into adulthood, including achievements or failures, interact with the ongoing brain and cognitive refinement.

Research into the implications of postponing traditional adult roles and continued adolescent and post-adolescent development is relevant for understanding the unique strengths and vulnerabilities of young adults. Although cognitive control functions may not reach their developmental peak until approximately 25 years of age, most people are capable of performing many adult functions adequately at an earlier age - apparently between 16 and 21. Which skills undergo perturbation at this age and how does the quality of the environment interact with brain changes in the development of cognitive skills? On the other hand, what are the overall implication and social costs associated with the lengthy and uncertain processes by which young people in post-industrial countries move into adulthood? For example, a large number of young adults not participating in the labour market and being economically active in their first 20-25 years of life could have a great cost on society (Billari & Liefbroer, 2010; Hendry & Kloep, 2007).

Continuous restructuration and changes in flexibility of the recruitment of different brain areas in combination with changes in social-cognitive processing can create certain vulnerabilities to engage in a harmful and reckless behaviour. Social studies have shown that even though most young people make it through these years with more or less positive experiences, some experiences will have tragic consequences. For instance, binge drinking which escalates during the early 20s is associated with unintentional (e.g. car crashes, falls) and intentional injuries (e.g. sexual assault, domestic violence, firearm injuries), alcohol poisoning, sexually transmitted diseases, cardiovascular diseases (e.g. high blood pressure, stroke), neurophysiological and neurocognitive deficits (Courtney & Polich, 2009; Taylor et al., 2010). At the same time, this is the period of life when numerous mental disturbances appear (Miguel-Hidalgo, 2013). The shift in relying on different brain circuits at this age may be especially relevant for individuals with psychopathology (Paus, Keshavan, & Giedd, 2008), and thus establishing patterns of typical developmental changes in brain structure and cognitive functions in young adulthood is of high priority. Mental disorders at this age are common and often comorbid and may be particularly harmful to education and employment in this age group.

One of the problems in finding answers in currently available evidence lies in the selection of the age groups since almost all available developmental studies so far have collapsed across 18 to 30 year-olds. This may represent a good frame of reference for the examination of broad changes that occur between different life-stages, however, age-specific patterns of change still remain largely unknown (Crone & Ridderinkhof, 2011). Future studies should carefully select age groups on the basis of available findings and theoretical frameworks in order to acquire the complete developmental picture.

Legal age boundaries are obviously not the same around the world, and age of majority does not depend on the mental or physical maturity of an individual. There is no global consensus regarding the youngest age at which a person is considered to knowingly commit a criminal act and thus can be tried and convicted of a criminal

offence. While the discussion on culpability, brain and cognitive development is still ongoing, evidence taken from developmental neuroscience studies have already affected some legal proceedings, and most scientists from various fields support the need for special consideration while prosecuting and sentencing adolescents under the age 18 (Steinberg, 2013). However, if we rely on evidence from neuroanatomical and functional development which show a slow maturation of cognitive control functions, like impulse control, and underlying brain structures responsible for adult behaviour during the early 20s, does the same apply to young adults? Considerable evidence indicates that brain and behavioural plasticity does not end in adolescence. Much more research which directly links age differences in brain structure and function to behaviours in certain legally relevant situations is needed.

Although the field of developmental cognitive neuroscience has made significant progress in our understanding of adolescent and post-adolescent brain development, future studies would benefit from researching how social context might moderate these findings. Longitudinal studies, including diverse samples and focusing on how associations between neural systems, cognitive skills and behaviour are moderated by environmental characteristics (e.g. social context, peer influence) could help in addressing some important limitations in the brain and cognitive development in the literature on young adulthood. Integration of neurobiological, psychological, and socio-cultural paradigms could advance our understanding of the complexity of the transitioning into adulthood, and better inform policies and treatments aimed at supporting more positive development across the lifespan.

Conclusion

The aim of this review was to use an interdisciplinary approach to tap into the issue of transition to adulthood by integrating recent findings from neuroscience and cognitive psychology while considering various social and legal markers of adulthood. Social, economic, and demographic changes over the past 50-60 years have resulted in dramatic changes in what occurs during the late teens and through the twenties for most young people in industrialized societies, leading to more flexible, variable, and less uniform pathways into adulthood. A great variability in defining the age of majority through legal definitions of adulthood across countries make determining when adulthood begins even more complicated.

Neurobiological models of brain maturation have made great advancements in understanding the development of brain structure across the lifespan, demonstrating protracted postnatal brain development, with considerable changes in cerebral cortical and subcortical structures, as well as changes in grey matter and white matter area, thickness and connectivity. Research that made use of cognitive control paradigms combined with neuroimaging provided evidence that brain regions that are typically associated with cognitive control show developmental changes

throughout adolescence and early young adulthood, in line with changes in the efficiency of exerting cognitive control over behaviour. Theoretical frameworks which we can borrow from cognitive psychology in order to interpret these findings are quite limited since they mostly focus on early stages of human life. Despite the mutual interest in better defining the transition period between adolescence and adulthood, research areas are still largely separated, leaving gaps in our knowledge and understanding of strengths and vulnerabilities of young adults. It seems that the time has come when we simply cannot afford to ignore converging interdisciplinary findings from multiple research domains anymore.

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Kada postajemo odrasli? Interdisciplinarni pregled teorija, istraživanja i novih dostignuća

Sažetak

Brojne su teorije razvojne psihologije, poput psihoanalitičke, bihevioristične ili kognitivističke, pokušale objasniti kako ljudi sazrijevaju i mijenjaju se tijekom života. Ove su teorije usmjerene na rane životne faze – od djetinjstva do adolescencije – ostavljajući dojam kako nakon adolescencije ne dolazi do značajnijih skokova u razvoju. Međutim, istraživanja su ljudskog razvoja u posljednjih 20-ak godina pokazala kako je sazrijevanje puno složenije te vremenski dugotrajnije nego se prethodno smatralo. Cilj je ovoga pregleda bio interdisciplinarnim pristupom istražiti pitanje prijelaza u odraslu dob prikazom najnovijih rezultata istraživanja o sazrijevanju mozga i kognitivnih sposobnosti iz područja neuroznanosti i kognitivne psihologije istovremeno razmatrajući tradicionalne i zakonom određene granice odraslosti. U prvom se dijelu rada raspravlja o određenim pitanjima vezanim uz definiranje razdoblja odraslosti kroz društvene i pravne okvire. Zatim se navodi kako produljeno strukturalno i funkcionalno sazrijevanje mozga utječe na kognitivne sposobnosti, naglašavajući potrebu i vrijednost istraživanja načinā na koje ove promjene mogu utjecati na donošenje važnih odluka tijekom rane odrasle dobi, a koje mogu imati dalekosežne posljedice. Konačno, na temelju se dokaza iz postojećih istraživanja ističe važnost prihvaćanja i integriranja nalaza iz različitih istraživačkih disciplina kako bi se bolje razumjela snaga i ranjivosti mladih osoba na pragu odrasle dobi.

Ključne riječi: produljeni razvoj mozga, interdisciplinarni pristup, mlada odrasla dob, adolescencija, kognitivne sposobnosti, sazrijevanje

¿Cuándo nos hacemos mayores? Revisión de teorías, investigaciones y nuevos logros desde el punto de vista interdisciplinario

Resumen

Numerosas teorías de la psicología de desarrollo, como la teoría psicoanalítica, conductual o cognitivista, han tratado de explicar cómo la gente madura y cambia durante la vida. Estas teorías se han enfocado en etapas tempranas de vida – desde la niñez hasta la adolescencia – dejando la impresión que después de la adolescencia no hay saltos significativos en el desarrollo. Sin embargo, las investigaciones del desarrollo humano en los últimos veinte años han demostrado que la maduración es un proceso mucho más complejo y duradero de lo que se suponía antes. El objetivo de este trabajo fue, a través de un enfoque interdisciplinario, investigar la transición a la edad adulta a través de los resultados recientes de las investigaciones en el campo de neurociencia y psicología cognitiva sobre la maduración del cerebro y las habilidades cognitivas, a la vez teniendo en cuenta los límites tradicionales y legislativos de la edad adulta. En la primera parte del trabajo se discute sobre ciertas cuestiones relacionadas con cómo definir la edad adulta a través de los marcos sociales y legales. Luego investigamos en qué modo la maduración estructural y funcional prolongada del cerebro influye en las habilidades cognitivas, acentuando la necesidad y el valor de investigaciones del modo en el que estos cambios pueden influir en la toma de decisiones importantes durante la edad adulta temprana, y que pueden tener consecuencias a largo plazo. En fin, a base de las pruebas de investigaciones existentes, acentuamos la importancia de aceptar e integrar los hallazgos de diferentes disciplinas de investigación para entender mejor las fuerzas y la vulnerabilidad de personas jóvenes que están a punto de pasar a la edad adulta.

Palabras clave: desarrollo de cerebro prolongado, enfoque interdisciplinario, edad adulta temprana, adolescencia, habilidades cognitivas, maduración

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