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The Neuroscience of Social Cognition in Teenagers: Implications for Inclusion in Society

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Summary

Recent brain imaging studies have demonstrated that the human brain continues to develop throughout the adolescent years. Although there are differences between male and female teenagers in terms of the time course of neural development, similar brain areas undergo significant restructuring in both sexes. Brain regions in which development is particularly protracted include the prefrontal cortex and the temporal-parietal cortex. These regions are involved in a number of cognitive functions, including decision-making and social cognition (the understanding of other people). The development of these brain regions might contribute to behaviours typically associated with the teenage years, such as increased risk-taking, susceptibility to peer pressure, and reduced self-control. Recent studies have investigated the development of social cognitive processes during adolescence. Research suggests that differences at the neural level between adolescents and adults may also impact on the experience of social emotions, and on the ability of teenagers to reflect on their own and others' point of view. These findings have potentially important implications for how we as a society treat this age group. For example, research on decision-making and impulse control might influence questions of criminal responsibility and anti-social behaviour. Additionally, future research might play a role in shaping educational and social policy, with a view to encouraging a more socially competent and responsible generation of teenagers, fully included in society.

1. Development of the brain during adolescence

Adolescence in humans is the period of psychological and social transition between childhood and adulthood. The beginning of adolescence, around the onset of puberty, is characterised by dramatic changes in hormone levels and, as a result, in physical appearance. This period of life is also characterised by psychological changes in terms of identity, self-consciousness and mood. After puberty, children become more aware of the opinions and emotions of both themselves and other people around them. The typical teenager is more moody and uncommunicative than a younger child (at least towards adults), and may take unnecessary risks. In addition, there are educational changes: some children go through an educational performance dip in Year 8 (age 12-13). Hormonal fluctuations alone might not account for these changes. Recent neuroscience research shows that there are also dramatic transformations in the brain during adolescence.

Much has been known about early brain development since experiments on animals carried out in the 1950s and 1960s. One major developmental process affects the 'wiring' of brain cells (neurons) – the intricate network of connections (synapses) between neurons. Early in development, the brain begins to form new synapses, so that the synaptic density – the number of synapses per unit volume of brain tissue – greatly exceeds adult levels. This process of synaptic proliferation, 'synaptogenesis', lasts up to several months, depending on the species of animal (Rakic et al., 1986; Bourgeois et al., 1994).

The increase in the number of synapses is followed by a period of synaptic elimination (or pruning) in which excess connections wither away. This process is pre-programmed to a large extent – it will happen in all environments. However, the environment can also influence synaptic pruning (Hubel and Wiesel, 1964), in that frequently-used connections are strengthened and infrequently-used connections eliminated. Indeed, this research has been used to argue that ages zero to three represent a 'critical period' for brain development. However, this argument neglects the fact that the animals in which this early development research was carried out, such as cats and monkeys, do not go through the same extended developmental period as humans, and are sexually mature at a much younger age.

This research suggested that brain development is particularly sensitive to environmental influence very early in life. It was not until the 1970s that research on post-mortem human brains revealed that some areas of the human brain, in particular the frontal cortex, continue to develop well beyond childhood. The frontal cortex is the area responsible for cognitive abilities such as the ability to make plans, remember to do things in the future, multi-task and inhibit inappropriate behaviour (executive functions). The frontal cortex also plays an important role in self-awareness and understanding other people. Peter Huttenlocher, at the University of Chicago, collected post-mortem brains from humans of all ages and found that the frontal cortex was remarkably different in the brains of pre-pubescent children and post-pubescent adolescents (Huttenlocher et al., 1979; 1983; 1997). While in sensory brain areas such as the visual cortex, synaptogenesis and synaptic pruning occur relatively early and synaptic density has reached adult levels by mid-childhood, synaptic reorganisation in the frontal cortex continues much later, well into adolescence. Huttenlocher found that the number of synapses in the frontal lobe is high at around puberty, after which their number decreases (due to synaptic pruning) throughout adolescence.

Another developmental mechanism that occurs for several decades in the frontal cortex is myelination. As neurons develop, they build up a layer of myelin on their axon (the long fibre transmitting signals from each brain cell). Myelin is a fatty substance that insulates the axons and vastly increases the speed of transmission of electrical impulses from neuron to neuron. Whereas sensory and motor brain regions become fully myelinated in the first few years of life, axons in some cortical regions, particularly the frontal and parietal lobes, continue to be myelinated well into adolescence in the human brain (Yakovlev and Lecours, 1967). This finding suggests that the transmission speed of neurons in these areas may increase after puberty.

1.1. *Recent MRI studies of the developing brain*

Until recently, the structure of the human brain could be studied only after death. In recent years, non-invasive brain imaging techniques, particularly Magnetic Resonance Imaging (MRI), have enabled scientists to study development of the living human brain (see also the Review by Paus). In the past decade, a number of MRI studies have provided further evidence of the ongoing maturation of the cortex into adolescence and even into adulthood. These studies show that the amount of white matter in various cortical regions, including the frontal cortex and temporo-parietal cortex, increases between childhood and adulthood (Giedd et al., 1999; Paus et al., 1999; 2000; Durston et al., 2001; see also Review by Paus, 2001). Myelin appears white in MRI scans. Therefore, the increase in white matter seen to occur throughout adolescence may represent an increase in axonal myelination.

At the same time, there is a change in the volume of grey matter (made up of cell bodies, dendrites and synapses) in various cortical regions during adolescence (Giedd et al., 1999; Sowell et al., 1999a; 1999b; Gogtay et al., 2004). Several large MRI studies, which have acquired brain scans from hundreds of people of different ages, have consistently shown that grey matter volume in the frontal cortex increases gradually during childhood and peaks at around the onset of puberty (around 11 in girls and 12 in boys (Giedd et al., 1999)). This is followed by a gradual decrease in the volume of grey matter during adolescence and early adulthood. It has been suggested that this pattern of grey matter development may in part be due to an increase in the number of synapses during childhood, followed by synaptic pruning during adolescence (e.g. Giedd et al., 1999). However, it has also been argued that the apparent loss of grey matter during adolescence is simply result of intracortical myelination, and has little to do with the connections between brain cells (see Paus Review, 2001, for details).

2. Cognitive development during adolescence

The brain regions that undergo particularly protracted development during adolescence, that is prefrontal and temporo-parietal cortices, are involved in a variety of cognitive abilities, including executive functions and social cognition. In the past few years, empirical research has looked at the cognitive changes that occur during adolescence. We do not as yet know how these relate directly to the structural brain changes described above, but research in this area is rapidly progressing.

2.1. *Development of self-concept during adolescence*

Anecdotal evidence and self-report data indicate that children become progressively self-conscious and concerned with other people's opinions as they go through puberty and adolescence (Adams and Berzonsky, 2003). The period of adolescence seems to involve both the establishment of a sense of self as well as a process of orienting towards others. The emergence of the social self is marked by a period of heightened self-consciousness, during which adolescents become preoccupied with other people's concerns about their own actions, thoughts and appearance. Social psychological studies have investigated changes in social thinking during adolescence and emphasise that this phase is characterised by a focus on "what other people think" (e.g. Lapsley and Murphey, 1985).

Social psychologists have posited several theories regarding this apparent increase in social and emotional sensitivity. Elkind's (1967) twin constructs, the Imaginary Audience (IA) and Personal Fable (PF) have been particularly influential. According to the IA theory, adolescents believe that everyone is as concerned about their behaviour as they are, and construct an abstract (and imaginary) audience observing their every move. The PF, on the other hand, is the tendency for adolescents to believe they are unique, invulnerable, and destined for greatness. Between them, the IA and PF cover many behaviours regarded as particular to adolescence: heightened self-consciousness; increased concern with the opinions of others and susceptibility to peer pressure (IA); and reckless behaviours such as drug use and unprotected sex (PF). Although it is generally accepted that many (though not all) adolescents go through a phase of constructing IAs and PFs, there is little consensus as to why they do so, or the underlying neural basis (Vartanian, 2000).

Elkind's (1967) own explanation was that the IA and PF arise from cognitive development between childhood and adolescence, and that this phase is characterised by 'cognitive egocentrism' i.e. a difficulty in differentiating one's own thoughts from those of others. The idea of a developing 'self-concept' is at the centre of many theories of adolescent social adjustment. Although the precise definition varies between studies, it is generally conceptualised as the way in which individuals view and treat themselves, and is seen as a product of interpersonal interactions (Benjamin, 1993; Ybrandt, 2008). A recent study found that having a negative self-concept (high scores on self-hate, self-neglect and self-blame) was associated with both internalising behaviours such as depression and anxiety, and externalising behaviours such as delinquency and aggression (Ybrandt, 2008). Therefore, it is important that adolescents are supported emotionally as they develop their self-concept. While such findings have immediate real-world applicability, however, they tell us little about the underlying brain mechanisms. Furthermore, it is difficult to disentangle cause and effect. Does having a negative self-concept cause depression and anxiety, or *vice versa*? Or are both caused by a third factor?

2.2. *The development of perspective-taking during adolescence*

The brain regions that undergo the most significant development during adolescence include those areas involved in self-awareness and in the ability to understand other people's perspectives. Given that the social environment dramatically changes during adolescence, and that the brain undergoes a restructuring process, it might be expected that social cognitive abilities such as self-awareness and perspective-taking develop during this period.

We recently investigated the development of perspective-taking during adolescence (Choudhury et al., 2006). Pre-adolescent children (age nine years), adolescents (age 13 years) and adults (age 24 years), were tested using a perspective-taking task. In the First Person Perspective (1PP) condition, the participant was asked to imagine how s/he would feel in various scenarios. An example of such a scenario was: "You just had an argument with your best friend. How do you feel?" In the Third Person Perspective (3PP) condition, the participant was asked how someone else would feel in the same set of scenarios. The participant was asked to choose one of two possible emotions in answer to each question, as quickly as possible. The results demonstrated that the difference in reaction time (RT) between 1PP and 3PP decreased significantly with age. The difference in RT in both groups of younger participants was larger and spread almost equally in both directions, whereas among adults there was little difference in timing for 3PP and 1PP. A similar RT to 3PP and1PP, as shown by the adult group, is likely to indicate the highest proficiency in perspective-taking. In contrast, the most pronounced difference in RT between 1PP and 3PP, seen in the pre-adolescent group, would indicate relatively inefficient processing. It might be speculated therefore that, prior to adolescence, the difference in RT reflects an immature cognitive mechanism for perspective-taking. Whether this response pattern among pre-adolescents is a result of a relative difficulty in differentiating between the first- and third-person, or because children of this age group are less inclined, or find it more difficult, to enter into another person's 'mental shoes', requires further investigation. The differences between age groups may also be influenced by differences in social experience. Compared with children and adolescents, adults are generally more skilled at instinctively inferring the perspectives of other people. Perhaps adults show no difference between RTs for 1PP and 3PP as a result of their mature neural circuitry supporting social cognition, as well as their greater social experience.

2.3. *Functional development of the social brain during adolescence*

Recent functional neuroimaging studies investigating social brain development during adolescence have revealed both increases and decreases in brain activity as a function of age. However, there is some indication that, for social cognitive tasks, activity in the frontal cortex increases between childhood and adolescence, and then decreases between adolescence and adulthood. Many of these studies have investigated the neural processing of emotion recognition. Female (but not male) participants showed increased activation in dorsolateral prefrontal cortex (PFC) in response to fearful faces between childhood and adolescence (Killgore et al., 2001). Additionally, a recent study reported increased activity in PFC (bilaterally for girls; right-sided for boys) in response to fearful faces between age eight and 15 (Yurgelun-Todd and Killgore, 2006). In contrast, another study of face processing found that attention to a non-emotional aspect of fearful relative to neutral faces was associated with increased activity in orbitofrontal cortex in adolescents compared to adults (Monk et al., 2003). These fMRI results suggest that the brain's emotion processing system continues to develop during adolescence.

A recent fMRI study investigated the development of high-level communication using an irony comprehension task and found that children (aged between nine and 14) engaged frontal regions (medial PFC and left inferior frontal gyrus) more than did adults (Wang et al., 2006). A similar result was obtained in a study in which we investigated the development during adolescence of the neural network underlying thinking about intentions (Blakemore et al., 2007). In this study, 19 adolescent participants (aged 12.1-18.1 years) and 11 adults (aged 22.4-37.8 years) were scanned using fMRI while answering questions about intentional causality ("Which action would you take, given a particular intention?") or physical causality ("What physical event would occur, given another physical event?"). In both adults and adolescents, answering questions about intentional causality *versus* physical causality activated the 'social brain' network, including medial PFC (MPFC), superior temporal sulcus (STS) and temporal poles.

However, there were also differences between the two groups. During intentional relative to physical causality, adolescents activated part of the MPFC more than did adults, whereas adults activated part of the right STS more than did adolescents. These results suggest that the neural strategy for thinking about intentions changes between adolescence and adulthood. Although the same neural network is active, the relative roles of the different areas change, with activity moving from anterior (medial prefrontal) regions to posterior (temporal) regions with age. One possible explanation for the decrease in prefrontal activity between adolescence and adulthood in these studies is that the PFC is still being organised during adolescence, and is therefore less efficient: more activity is required to achieve the same task (see Blakemore, 2008 for review). Further studies are needed to explore this possibility.

2.4. *Susceptibility to peer influence*

Adolescents are particularly susceptible to peer influence (Steinberg and Silverberg, 1986). The consequences of peer influence have been well researched, both in the lab and in a socio-cultural context. For example, it has been found that, while adults who commit crimes do so alone, most adolescent crimes are committed with peers (Zimring, 1998). This suggests that peer influence may contribute to teenage engagement in inherently risky activity (although it may also reflect the fact that teenagers spend more time with peers than do adults). A recent laboratory study by Gardner and Steinberg (2005) looked at incidences of risky driving in a car simulation video game when adolescents and adults played either alone or with two friends present. It was found that the presence of peers led to an increase in risky driving, for example, failing to stop at a yellow traffic light, specifically in adolescents. Levels of risk-taking did not differ for adult participants depending on whether they were alone or with peers, and adolescents showed the same level of risk-taking as adults when they were alone. However, in the presence of peers, the number of risks taken was greatly increased (see Figure 1).

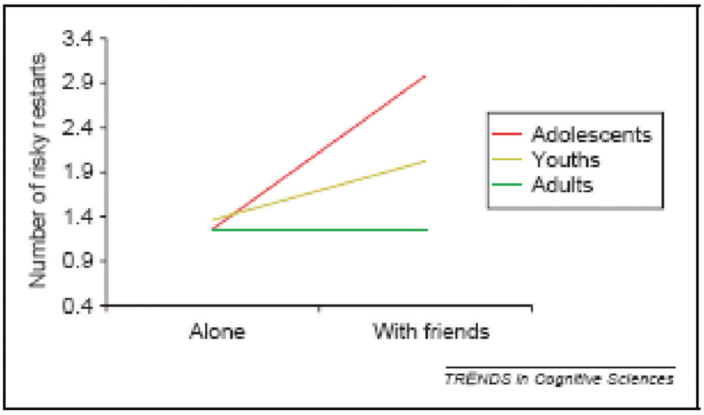

Figure 1 The number of risks taken by adults did not differ depending on whether participants were alone or with friends. However, adolescent risk-taking increased dramatically when participants were with friends. Taken from Steinberg et al. (2005).

These findings suggest that decision-making and planning are more fallible in adolescence when in the presence of peers. The immaturity of the PFC could explain these consequences, in that the developing system is less able to cope under added emotional pressure. This is a plausible but speculative idea that needs further work. At present, cognitive neuroscience has not addressed whether the immaturity of PFC could also explain the susceptibility to peer pressure in the first place.

However, emerging evidence suggests that the importance attached by the brain's reward systems to social interaction during adolescence may play a role – a possibility we discuss in the following section.

2.5. *Reward-processing during adolescence*

Adolescence in animals does not mirror every aspect of human adolescence. However, observing animals can be a useful way to learn about some aspects of this period of life. For example, some of the social and hormonal characteristics of human adolescence have parallels in rodents or monkeys. Research on animals has shown that reward-processing differs between adolescence and adulthood. Adolescent rodents display higher sensitivity to the short-term rewarding effects of substances such as ethanol (alcohol) and nicotine than their adult counterparts. Adolescent mice, for example, show a greater tendency to return to a place where they previously received nicotine than adult mice (Kota et al., 2007). Adolescent mice show enhanced sensitivity to the locomotor-stimulating and anxiety-alleviating effects of ethanol, relative to adult mice (Hefner and Holmes, 2007). Therefore, some rewarding substances may be processed differently in the adolescent brain.

While certain chemical substances may be rewarding, one potent reward is novelty itself. Animals including rodents, monkeys and humans prefer to experience a few new (novel) things from time to time (Wilson and Rolls, 1993). Adolescent rodents show increased novelty-seeking, as well as decreased novelty-induced anxiety and greater exploration in novel situations, compared with older and younger animals (e.g. Adriani et al., 1998; for a review, see Laviola et al., 2003). Therefore, adolescent rodents are more likely to seek out new (and potentially risky) stimuli and experiences than are older or younger animals. Whether this applies to humans has not been addressed.

Another particular feature of adolescence is sensitivity to social reward. At the onset of adolescence, rodents begin to disperse and integrate into new social groups (Gerlach, 1998; Pocock et al., 2005; Berry et al., 1992). Adolescent rats engage in more social play than do younger or older animals (Spear and Brake, 1983), while adolescent non-human primates play less than their younger counterparts but show more affiliative behaviours such as grooming, huddling and pair-sitting (Ehardt and Bernstein, 1987). Human adolescents report that they are most happy when talking with peers, and spend increasing amounts of time with peers and less time with their families (Csikszentmihalyi et al., 1977). This increased affiliation shown by adolescents towards their peers may be an adaptive strategy for survival, as the tolerance shown by adults towards younger individuals is replaced by competition and increased aggression, at least in non-human primates (de Waal, 1993).

While increasing pleasure is derived from social interaction with peers, adolescents may become more sensitive to the pain of social exclusion. This could lead to increased sensitivity to peer pressure. Coupled with increased risk-taking and novelty-seeking, as well as potentially different neural sensitivities to substances such as ethanol, nicotine and perhaps other drugs, these changes in the processing of social reward are likely to contribute significantly to the particular vulnerabilities of adolescents as a group. We should remember, however, that a moderate degree of risk-seeking behaviour and experimentation is probably healthy and normative during the adolescent years (Spear, 2000), and that sensitivity to peer influence is also a positive factor in adolescent social behaviour.

Accumulating evidence from functional neuroimaging studies supports the idea that aspects of adolescent reward-processing have their basis in neuro-maturational events. The reward circuitry of the brain responds differently to risk and monetary reward in adolescents as compared to adults. In particular, regions of the PFC that respond to decision outcomes are under-activated by adolescents relative to adults, when choosing whether or not to play low-penalty gambles for money (Bjork et al., 2007). A behavioural consequence of this could be that adolescents are relatively insensitive to moderate, everyday, risky situations, although more research needs to be carried out to investigate this idea. In addition, the neural circuits responsible for inhibiting inappropriate social behaviour show less functional integration in adolescents compared with adults. In an adolescent, the brain regions responsible for impulse control are not activated in concert, as they are in an adult brain – they do not 'talk to each other' as much (Stevens et al.. 2007).

3. Gender differences

Cognitive changes during adolescence may not be equally applicable to males and females, or they may follow different time courses. Anatomically, sex differences have been reported in grey and white matter volume during adolescence (Yurgelun-Todd et al., 2002), as well as in the time course of neural development (Giedd et al., 1996; 1997), with grey matter volume peaking at around age 11 in girls and 12 in boys. Links between anatomical differences and behaviour are also apparent. A recent study (Silveri et al., 2006) looked at impulse control (the ability to control and regulate our behaviour), and found that different regions of white matter were associated with task performance in male and female teenagers. The findings suggest subtle differences in the brain networks recruited for cognitive control by males and females during development. Such gender differences at the neural level may help to explain behavioural differences in executive processes such as decision-making and risk assessment. For example, several studies have found that, relative to females, male adolescents give more weight to the potential benefit of a risk than its potential costs (Gardner and Steinberg, 2005), and are also more prone to risk-taking in the presence of peers (Parsons et al., 2000).

Gender differences in social behaviour have also been well-documented during the adolescent years. For example, young adolescent females are much more likely to use social aggression such as ostracism during interpersonal interaction (Williams et al., 2000; Cairns et al., 1989), while males tend to use physical aggression. Additionally, teenage girls who have a negative self-concept (high levels of self-hate, self-neglect and self-blame) are more likely to engage in internalising behaviours, i.e. depression, anxiety and withdrawn behaviour, while boys tend to engage in more outwardly-aggressive externalising behaviours (Moffitt et al., 2001; Roussos et al., 2001).

The next step is to link these social observations with what we are learning about the brain. Brain development patterns may shed light on gender-related differences in the onset of various mental illnesses (Silveri et al., 2006; Kovacs et al., 2003; Evenson et al., 1993). This is especially likely given that the tendency for certain disorders to be more prevalent in one gender than the other first emerges during adolescence (Angold et al., 1998), for example, higher incidences of depression/anxiety in females. However, psychosocial factors such as gender expectations and differential exposure to social stressors (Kendler et al., 2001) may be important in explaining gender differences in both clinical and typical populations. An important goal, therefore, for cognitive neuroscience is to integrate research on the brain with findings from the social and behavioural sciences.

4. Implications for inclusion in society

The teenage years are a time of marginalisation for many, and it could be argued that highlighting differences in behaviour and neuroanatomy merely serve to increase the sense in which members of this age group are not yet fully active members of society. However, despite meeting the material needs of this age group better than at any previous point in human history, many developed countries, including the UK, are seeing rising rates of mental illness, disaffection and criminal behaviour (UNICEF, 2007). Improving knowledge of adolescent development at the neural, as well as psychosocial, level will only increase the chances of helping those who need it.

In practical terms, research on the development of the neural structures underlying the appraisal of risk and reward may have implications for the criminal justice system (Blakemore and Choudhury, 2006; Greene and Cohen, 2004). Additionally, recent effort has been made to integrate findings about brain development into educational policy, both for special educational needs, such as autism and dyslexia, and for typical development (Goswami, 2006). One potentially positive implication of the neural development occurring during adolescence is that the teenage brain is well adapted to learning. Although a 'Year 8 dip' in academic performance has been reported, this might correspond, at least in part, to the reorganisation of the brain so that it can learn more efficiently. Appropriate education is crucial during the adolescent years. The data suggest that it is not too late for those still struggling with educational attainment.

An important next step is to extend these efforts to the pastoral side of education, in order to inform anti-bullying and extra-curricular policies. One purely speculative possibility is that, just as the environment influences synaptic pruning in the first few years of life, so might it have an impact on the pruning that occurs in the frontal cortex during adolescence. There are no tools as yet to look at pruning in the living human brain. However, if the environment influences synaptic pruning during adolescence, this has implications for what kind of experiences adolescents should encounter: both academically and socially. Secondary school is often socially stressful (Erath et al., 2007), just at the time when the social brain is undergoing profound development. Providing a social environment at school that is more in line with neural maturation might be useful. It might be fruitful to include in the curriculum some teaching on the changes occurring in the brain during adolescence. Adolescents might be very interested to learn about the changes that are going on in their brains.

Medical policy could also benefit from research on the adolescent brain. For example, treatment of substance abuse disorders may require modification for this population in light of differences in risk and reward circuitry. Similarly, mood disorders such as depression and anxiety may differ between adolescence and adulthood due to differences affecting regulation and emotional sensitivity. Implications are also raised for young people who take recreational drugs such as cannabis, as the effects they have on the developing teenage brain are likely to be different to those on the adult brain, and may have longer-term consequences. Indeed, regular cannabis use is associated with a significant increase in the risk of a later schizophrenia diagnosis, and this risk is even higher if the onset of use occurs during adolescence (Arseneault et al., 2004). This may well be because the brain is more vulnerable to the effects of the drug during development (Pope et al., 2003). Education of young people based on new findings about the brain may act as a more effective deterrent against heavy and regular use than current techniques.

5. Conclusions

Research on neuro-cognitive development during adolescence is still a relatively new field. However, in the past few years there have been some important developments.

Research is currently exploring how the brain changes and how these changes might help to explain certain aspects of typically teenage behaviour, such as risk-taking and emerging competence in interpersonal interactions.

In turn, these findings might contribute to improving the quality of education and pastoral care for this age group, and may also have implications for the way young people are seen in the eyes of the law and are treated by the medical profession.

In all, the research discussed throughout this review serves to highlight that adolescents are a distinct sector of society with specific needs. Future policies should aim to reflect this.

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