

Adolescent suicide and suicidal behavior

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This review examines the descriptive epidemiology, and risk and protective factors for youth suicide and suicidal behavior. A model of youth suicidal behavior is articulated, whereby suicidal behavior ensues as a result of an interaction of socio-cultural, developmental, psychiatric, psychological, and family-environmental factors. On the basis of this review, clinical and public health approaches to the reduction in youth suicide and recommendations for further research will be discussed. **Keywords:** Suicide, children, adolescents, suicidal behavior, risk factors.

During the past quarter-century, suicide among the young has emerged as a significant global public health problem. In many countries, youth suicide is one of the leading causes of death, having increased markedly from the 1960s through the early 1990s (Gould, Greenberg, Velting, & Shaffer, 2003; World Health Organization, 2002).

Progress has been made in our understanding of the phenomenology and risk factors of adolescent suicide and suicidal behavior (Beautrais, 2000b; Evans, Hawton, & Rodham, 2004; Gould et al., 2003; Pelkonen & Marttunen, 2003; Shaffer & Pfeffer, 2001). This report will first review the descriptive epidemiology of youth suicide and suicidal behavior. Then we examine risk for adolescent suicide and suicidal behavior with regard to salient domains: (1) mental and physical disorder; (2) personality and psychological traits; (3) family factors; (4) biology; (5) contagion; (6) access to lethal agents; and (7) intervention and clinical management. Finally, public health approaches to the reduction in youth suicide and further research will be discussed.

Terminology

In this review, definitions of suicidal thoughts and behavior developed by O'Carroll et al. (1996) and adopted by the Institute of Medicine (2002) will be used (Goldsmith, Pellmar, Kleinman, & Bunney, 2002). *Suicidal ideation* refers to thoughts of harming or killing oneself. *Attempted suicide* is a non-fatal, self-inflicted destructive act with explicit or inferred intent to die. *Suicide* is a fatal self-inflicted destructive act with explicit or inferred intent to die. *Suicidality* refers to all suicide-related behaviors and thoughts including completing or attempting suicide, suicidal ideation or communications. This review will focus on the spectrum of suicidality, from suicidal ideation to suicidal behavior, with passive thoughts of death and completed suicide representing extreme ends of the risk spectrum (Brent et al., 1988; Gould et al., 1998; Lewinsohn, Rohde, & Seeley, 1996; Reinherz et al., 1995). Non-suicidal self-harm, sometimes referred to

as 'parasuicide,' is viewed as distinct from suicidal behavior and most commonly involves self-cutting without suicidal intent (Simpson, 1975). Factors associated with parasuicide will not be reviewed, although often, non-suicidal self-harm and suicidal behavior co-occur (for a recent review of parasuicide, see Welch, 2001).

Descriptive epidemiology of youth suicide and suicidal behavior

Suicidal ideation

The point prevalence of suicidal ideation in adolescence is approximately 15–25%, ranging in severity from thoughts of death and passive ideation to specific suicidal ideation with intent or plan (Grunbaum et al., 2004). The latter is much less frequent, with annual incidence rates of 6.0% and 2.3% in adolescent girls and boys, respectively (Lewinsohn et al., 1996).

Suicide attempt

Lifetime estimates of suicide attempts among adolescents range from 1.3–3.8% in males and 1.5–10.1% in females, with higher rates in females than males in the older adolescent age range (Andrews & Lewinsohn, 1992; Fergusson & Lynskey, 1995b; Lewinsohn et al., 1996). Annual suicide attempt rates among adolescents requiring medical attention are on the order of 1–3% (Grunbaum et al., 2004). However, the actual number of suicide attempts may be underestimated because many youth attempters will not seek treatment or will not be accurately documented (Hawton & Goldacre, 1982b; Lewinsohn, Rohde, & Seeley, 1994).

Repetition of suicidal behavior

Suicidal behavior tends to be recurrent, and may be a harbinger of suicide completion. Estimates of the risk of repetition of suicidal behavior range from 10%

upon a 6-month follow-up to 42% upon 21-month follow-up, with a median recurrence rate of 5–15% per year (Goldston et al., 1999; Hawton & Catalan, 1987; Hawton, Zahl, & Weatherall, 2003). The rates of subsequent completed suicide among attempters are 0.5–1.0% per year, which are substantially elevated compared to the general population (Hawton et al., 2003; Otto, 1972).

Completed suicide

Table 1 gives the most recent youth suicide statistics from selected countries reporting mortality data to the World Health Organization (2002). Suicide rates in the Russian Federation and former Soviet states are especially high, along with New Zealand, Finland, and Ireland. These countries have rates of suicide two to three times higher than the United States, which is in the middle of the rates for the various countries selected.

Age and pubertal status

Suicide rates consistently increase from childhood to adolescence, perhaps because of the greater preval-

ence of psychopathology in adolescents, particular combinations of mood disorder and substance abuse, and the greater risk for suicide conveyed by psychopathology in older adolescents (Brent, Baugher, Bridge, Chen, & Chiappetta, 1999; Groholt, Ekeberg, Wichstrom, & Haldorsen, 1998; Shaffer et al., 1996). Adolescents are also more cognitively capable of planning and executing a lethal suicide attempt, and show greater planning and intent than younger suicide victims (Brent et al., 1999; Groholt et al., 1998). For the same reason, cognitively precocious youths are overrepresented in younger suicide victims (Shaffer, 1974). Moreover, older adolescents receive more autonomy and less supervision and social support from parents, which may increase the opportunity for disconnection and make recognition of imminent risk less likely.

Gender

Rates of completed suicide for young females are lower than those for males in all countries for which data are systematically collected, with the exception being China (Table 1). This is in contrast with suicidal ideation and suicide attempts, where females have much higher rates than males after puberty (Fergusson, Woodward, & Horwood, 2000; Grunbaum et al., 2004). The gender difference in youth suicide is most likely due to the greater likelihood of males having multiple risk factors such as comorbid mood and alcohol abuse disorders, greater levels of aggression, and choice of more lethal suicide attempt methods, which make them more likely than females to make a lethal suicide attempt (Brent et al., 1999; Gould, Fisher, Parides, Flory, & Shaffer, 1996; Shaffer et al., 1996; Shaffer & Pfeffer, 2001). In countries such as China more females complete suicide than males, especially in rural areas where highly lethal insecticides are common and treatment facilities harder to access (World Health Organization, 2002).

Race and ethnicity

Rapid cultural transition may contribute to increases in youth suicide rates. Assimilation and loss of traditional cultural practices can increase alienation, intra-generational conflict, and create a situation in which an individual does not feel strongly affiliated with either the traditional or the alternative culture. For example, the increase in suicide in Chinese women may be related to family disruption and marginalization of women as a consequence of transition from a traditional agrarian to a modern urban capitalist society (Ji, Kleinman, & Becker, 2001; M. R. Phillips, Liu, & Zhang, 1999).

In the United States, rates of attempted and completed suicide are especially high among Native Americans (Anderson, 2002; Borowsky, Resnick, Ireland, & Blum, 1999; Wallace, Calhoun, Powell, O'Neil, & James, 1996), a pattern observed among

Table 1 Youth suicide rates in selected countries by age and sex^a

Country	Year	5–14 years			15–24 years		
		M	F	All	M	F	All
Lithuania	2002	1.6	0.4	1.1	59.4	5.9	33.1
Russia	2002	3.8	1.0	2.4	56.9	9.2	33.4
New Zealand	2000	1.0	0.3	0.7	30.4	5.7	18.2
Latvia	2002	2.7	0.0	1.4	29.8	4.1	17.2
Ireland	2000	0.3	0.0	0.2	25.3	6.5	16.1
Norway	2001	0.0	0.0	0.0	22.1	7.6	15.0
Australia	2001	0.3	0.3	0.3	20.7	4.8	12.9
Canada	2000	1.4	0.9	1.1	20.2	5.5	13.0
Austria	2002	0.4	0.4	0.4	20.1	3.6	12.0
Poland	2001	1.3	0.1	0.7	19.3	2.4	11.0
Switzerland	2000	0.9	0.2	0.6	18.5	4.9	11.8
Czech Republic	2001	0.7	0.3	0.5	17.2	2.6	10.1
Hungary	2002	0.7	0.5	0.6	17.0	3.6	10.5
United States	2000	1.2	0.3	0.7	17.0	3.0	10.2
Japan	2000	0.9	0.3	0.6	15.8	6.9	11.5
Germany	2001	0.8	0.3	0.5	12.4	2.7	7.7
France	1999	0.5	0.2	0.4	12.3	3.4	7.9
Israel	1999	1.0	0.0	0.5	11.4	1.3	6.5
Sweden	2001	0.3	0.5	0.4	11.2	3.6	7.5
United Kingdom	1999	0.1	0.0	0.1	10.6	2.5	6.7
Singapore	2001	1.2	0.8	1.0	9.7	7.6	8.7
Netherlands	2000	0.5	0.0	0.3	9.4	1.9	5.7
China	1999	0.5	0.5	0.5	9.0	6.8	7.9
(Hong Kong SAR)							
Argentina	1996	0.4	0.3	0.3	8.8	3.4	6.1
Spain	2000	0.3	0.2	0.2	7.7	1.5	4.7
Mexico	1995	0.5	0.3	0.4	7.6	2.0	4.7
Italy	2000	0.3	0.1	0.2	6.7	1.6	4.2
China (mainland, selected areas)	1999	0.9	0.8	0.8	5.4	8.6	6.9
Portugal	2000	0.0	0.0	0.0	3.7	1.0	2.4

^aRank-ordered by 15–24 male suicide rates.

Source of data: World Health Organization (2002)

indigenous peoples worldwide (Beautrais, 2001a; Boothroyd, Kirmayer, Spreng, Malus, & Hodgins, 2001; C. Cantor & Neulinger, 2000). Berlin (1987) found that those tribes with the highest suicide rates had higher rates of alcoholism, incarceration, unemployment, and lack of retention of traditional Native American culture.

Whites traditionally have had higher suicide rates than non-whites in the United States, but the gap has been narrowing due to an increase in youth suicide among African American males (Centers for Disease Control and Prevention, 2005; Joe and Kaplan, 2002; Shaffer, Gould, & Hicks, 1994). Assimilation and loss of traditional protective factors may also partially explain the class gradient in suicide among young African Americans, with risk increasing with higher social class (Gould et al., 1996). Although Hispanic youth in the USA are not disproportionately represented among suicide completers (Demetriades et al., 1998), they show higher rates of suicidal ideation and attempted suicide (Grunbaum et al., 2004).

Secular trends

During the past decade, there has been a significant decline in youth suicide in several countries (Table 2). Possible explanations for the recent decline in the USA and Australia may relate to more restrictive gun laws (Webster, Vernick, Zeoli, & Manganello, 2004). Pharmacoepidemiology studies have shown a relationship between the degree of increases in SSRI prescriptions and sales and the decline in youth suicide (Ludwig & Marcotte, 2005; Olfson, Shaffer, Marcus, & Greenberg, 2003), with a dose-response relationship between the degree increase in selective serotonin reuptake inhibitors (SSRIs) sales or prescriptions, and the extent of decline in the suicide rate.

Methods of suicide

The three leading methods of suicide among youth in the United States are firearms, hanging, and poisoning, respectively, whereas in most other Western countries hanging and vehicular exhaust predominate, followed by firearms and poisoning (Beautrais, 2000a; C. Cantor & Neulinger, 2000; Centers for Disease Control and Prevention, 2005). With limitations on availability of firearms, the United States and Australia have seen a decline in the use of firearms, partially offset by substitution of other methods such as hanging and vehicular exhaust (Beautrais, 2000a; Bridge, Barbe, & Brent, 2005; Centers for Disease Control and Prevention, 2004). Suicide by jumping is a relatively uncommon method of suicide in most countries (Gunnell & Nowers, 1997b), although jumping from a height is the primary method of choice for suicide completers in Hong Kong (Hau, 1993).

Table 2 Youth suicide rates in selected countries by age and year

Country	5-14 years		15-24 years	
	1990	2000	1990	2000
Eastern Europe/former Soviet Union				
Estonia	1.3	.5	17.2	18.1
Russia	1.4	2.7	17.8	33.7
Latvia	1.9	1.9	13.6	17.9
Hungary	1.7	.9	14.3	10.7
Poland	.6	.9	9.6	11.4
Czech Republic	.4	1.0	8.7	10.5
Northern Europe				
Finland	.6	.3	31.3	19.9
Norway	.8	.7	14.4	15.5
Sweden	.5	.2	10.1	8.7
Germany	.4	.4	9.5	7.7
Netherlands	.4	.3	5.9	5.7
English-speaking				
New Zealand	.4	.7	23.1	18.2
Australia	.2	.3	15.9	13.3
Canada	.8	1.1	15.0	13.0
United States	.8	.8	13.2	10.2
Ireland	.6	.2	9.3	16.1
United Kingdom	.03	.1	7.2	6.8
Catholic Europe				
Austria	.3	.9	15.4	13.9
France	.3	.6	9.3	7.9
Spain	.4	.2	4.5	4.7
Portugal	.3	.0	5.4	2.4
Italy	.3	.2	4.0	4.2
Asian				
Singapore	.7	1.2	10.4	7.1
Japan	.3	.6	7.0	11.5
Hong Kong	.2	1.4	7.1	6.5
Latin American				
Argentina	.6	.6	5.1	8.7
Mexico	.2	.5	3.1	5.4
Other				
Israel	.2	.5 ^a	5.0	6.5 ^a

^aRate for 1999.

Based on country groupings of Kelleher and Chambers (2003).
Source of data: World Health Organization (2002).

Risk factors for completed and attempted suicide

Suicide ideation

Longitudinal studies have shown that the more severe (high intent or planning) and pervasive (high frequency or duration) the suicidal ideation, the more likely such ideation is to eventuate in an attempt (Lewinsohn et al., 1996). Attempters who show persistent suicidal ideation, particularly with a plan or high intent to commit suicide or both, are at increased risk to reattempt (Goldston et al., 1999; Lewinsohn et al., 1996).

Previous suicidal behavior

A prior suicide attempt is the single most potent risk factor for youth suicide in both case-control and prospective studies, elevating the risk of a subsequent completion 10-60 fold (Brent et al., 1999;

Kotila & Lonnqvist, 1989; Marttunen, Aro, & Lonnqvist, 1992; Shaffer et al., 1996). The risk for repetition is highest in the first 3 to 6 months after a suicide attempt, but remains substantially elevated from the general population for at least 2 years (Goldston et al., 1999; Lewinsohn et al., 1996).

Lethality of the suicide attempt

Suicide attempters who make attempts of high medical lethality (e.g., hanging, shooting, or jumping) are at extremely high risk for completed suicide (Brent et al., 1988; Garfinkel, Froese, & Hood, 1982; Otto, 1972). However, an attempt of low lethality does not necessarily indicate low suicidal intent, especially in younger children whose cognitive immaturity makes it difficult to formulate and execute a suicidal plan. In an impulsive individual for whom a lethal agent such as a firearm or paracetamol is available, an attempt with relatively low intent may result in a medically serious and even fatal attempt (Brent et al., 1993f; Gunnell et al., 1997a).

Intent and motivation

Suicidal intent, or the extent to which the suicide attempter wishes to die, is a powerful discriminative and predictive variable for repetition of suicide attempts and completed suicide (Beck, Morris, & Beck, 1974; Brent et al., 1988; Hawton & Goldacre, 1982b). Suicidal intent consists of four orthogonal factors: (1) belief about intent; (2) preparation before attempt; (3) prevention of discovery; and (4) communication (Brent et al., 1988; Kingsbury, 1993). Items that discriminate between completers and attempters include evidence of planning, timing the attempt to avoid detection, confiding suicidal plans ahead of time, and expressing a wish to die (Brent et al., 1988).

Motivation is the reason given by the patient and family for the suicidal act. For the one-third of attempters with the highest suicidal intent, their motivation is to die or to permanently escape a psychologically painful situation (Hawton & Catalan, 1987; Kienhorst, De Wilde, Diekstra, & Wolters, 1995). Those attempters who wish to die, to escape a painful situation (e.g., an abusive home), or expect to reattempt are at high risk for recurrent suicide attempts (Cohen-Sandler, Berman, & King, 1982; Goldston et al., 2001). Often, motivations for engaging in suicidal behavior reflect difficulties with social skills and interpersonal effectiveness (Hawton & Catalan, 1987; Kienhorst et al., 1995).

Precipitant

The most common precipitants for adolescent suicidal behavior are interpersonal conflict or loss, particularly for youth with substance abuse (Brent et al., 1999, 1993e; Gould et al., 1996). Discord is a

risk factor for completed and attempted suicide (Beautrais, 2000b). The more unrelenting the discord, the more likely a suicide attempter is to repeat (Asarnow & Carlson, 1988). In youth with conduct disorder and substance abuse, legal and disciplinary problems are common precipitants for suicidal behavior and suicide, reflecting in part contributions that impulsivity, aggression, and substance use make to suicidal risk (Brent et al., 1999, 1993e; Marttunen, Aro, Henriksson, & Lonnqvist, 1994b).

Mental disorder

Any psychiatric disorder. Psychiatric disorder is present in nearly 90% of unselected adolescent suicide victims, and poses a 9-fold increased risk for suicide (Brent et al., 1988, 1993; Marttunen, Aro, Henriksson, & Lonnqvist, 1991; Shaffer et al., 1996; Shafii, Carrigan, Whittinghill, & Derrick, 1985; Shafii, Steltz-Lenarsky, Derrick, Beckner, & Whittinghill, 1988) (see Tables 3 and 4).

Similarly, in approximately 80% of community and referred cases of suicide attempts, there are associated psychopathological conditions (Andrews & Lewinsohn, 1992; Beautrais, Joyce, & Mulder, 1998a; Fergusson & Lynskey, 1995b; Gould et al., 1998; Kerfoot, Dyer, Harrington, Woodham, & Harrington, 1996; Reinherz et al., 1995). Moreover, chronicity and severity of disorder have been associated with increased suicidal risk (Brent et al., 1993b; Ryan et al., 1987).

Mood disorders. Mood disorders contribute substantially to risk of completed and attempted suicide in both genders (Beautrais et al., 1998a; Fergusson & Lynskey, 1995a; Garrison, Jackson, Addy, McKeown, & Waller, 1991; Gould et al., 1998; Joffe, Offord, & Boyle, 1988; Lewinsohn et al., 1994; Reinherz et al., 1995) (Tables 3 and 4). Bipolar disorder, especially in a mixed state, was a risk factor for completed suicide in some studies (Brent et al., 1988, 1993) but not others (Marttunen et al., 1991; Shaffer et al., 1996). Bipolar disorder, including bipolar II and bipolar NOS, greatly increased the risk of attempts in epidemiologic and clinical samples (Goldstein et al., in press; Lewinsohn, Klein, & Seeley, 1995).

Longitudinal studies also support associations between mood disorders and attempted and completed suicide (Weissman et al., 1999). In one prospective case-control study of adult subjects who had adolescent-onset MDD ($n = 73$) and controls with no evidence of past or current psychiatric disorder ($n = 37$), the 10-plus year mortality due to suicide of adults with adolescent-onset MDD was 7.7% versus 0% in controls, with a 5-fold increased risk of first suicide attempt (Weissman et al., 1999).

Substance use disorders. Substance abuse (alcohol/drug abuse) plays a significant role in youth

Table 3 Psychiatric disorder in young suicide victims (%)

	Shafii (1988)	Brent (1988)	Marttunen (1991)	Brent (1993)	Apter (1993)	Shaffer (1996)	Houston (2001)
Age range	11–19	13–19	13–19	13–19	18–21	≤20	15–24
No. of suicide completers	<i>N</i> = 21	<i>N</i> = 27	<i>N</i> = 53	<i>N</i> = 67	<i>N</i> = 43	<i>N</i> = 119	<i>N</i> = 27
Any psychiatric disorder	95	93	94	90	81	91	70
Any mood disorder	76	63	–	49	–	61	44
Major depressive disorder	38	41	23	43	54	32	15
Depressive disorder NOS	–	–	25	–	–	3	7
Dysthymia	10	22	4	–	5	13	–
Bipolar spectrum disorder	–	22	–	18	–	2	–
Adjustment disorder	–	–	21	–	7	5–6	–
Any substance abuse	62	41	–	27	0	35	7
Alcohol abuse	–	37	26 ^a	24	0	22	–
Drug abuse	–	30	4	13	0	25	–
Any anxiety disorder	–	15	4	12	7	27	0
PTSD	–	–	–	–	–	–	–
Panic disorder	–	0	–	–	–	–	–
Disruptive disorder	–	–	–	–	–	50	–
Conduct disorder	–	22	8	28	–	46	–
Attention deficit disorder	–	26	4	13	–	8	–
Eating disorder	–	–	–	–	–	4	0
Schizophrenia	–	–	6	0	7	3	11
Any Axis I Comorbidity	81	–	43	–	–	70	–
Comorbidity on Axis I and/or II	–	–	51	–	–	–	26
Comorbidity of mood and non-mood axis I disorders	43 ^b	44	–	23	–	5–13 ^c	–
No psychiatric diagnosis	5	7	6	10	19	9	30

^aAlcohol abuse or dependence; ^bmood disorder and substance abuse; ^clifetime rate.

suicide, especially in older adolescent males when comorbid with mood disorder or disruptive disorders (Allebeck & Allgulander, 1990; Brent et al., 1999; Renaud, Brent, Birmaher, Chiappetta, & Bridge, 1999; Shaffer et al., 1996; Shafii et al., 1988) (Tables 3 and 4). While most studies in the USA show substance abuse to be a major risk factor primarily in male suicide, Marttunen and colleagues (1991), in a Finnish study, found similar rates in males and females.

Substance abuse is also a risk factor for attempted suicide, mainly in older samples (Andrews & Lewinsohn, 1992; Beautrais et al., 1998a; Borowsky, Ireland, & Resnick, 2001; Fergusson & Lynskey, 1995a; Gould et al., 1998; Reinherz et al., 1995). Moreover, suicide attempters are more likely to have substance abuse/dependence disorders than suicidal ideators (Gould et al., 1998), suggesting that substance use may facilitate the transition from ideation to behavior.

Conduct disorder/Antisocial behavior. Disruptive disorders carry a 3–6 fold greater risk for youth suicide in case-control and longitudinal studies (Table 4), and are more likely to result in suicide in the presence of a current substance abuse disorder (Allebeck & Allgulander, 1990; Brent et al., 1993; de Chateau, 1990; Groholt et al., 1998; Kuperman, Black, & Burns, 1988; Renaud et al., 1999; Shaffer et al., 1996), and increase the risk for suicidal behavior as well (Andrews & Lewinsohn, 1992; Beautrais et al., 1998a; Fergusson & Lynskey,

1995b; Garrison, McKeown, Valois, & Vincent, 1993; Joffe et al., 1988; Reinherz et al., 1995).

Anxiety disorder. Anxiety disorders are associated with youth suicide and attempted suicide, although in some studies its contribution to suicidal risk is attenuated after controlling for mood disorder and other conditions (Shaffer et al., 1996). However, panic attacks may increase the risk for suicidal behavior, even after controlling for mood and other disorders (Gould et al., 1998; Pilowsky, Wu, & Anthony, 1999).

Post-traumatic stress disorder (PTSD). No psychological autopsy study of young suicide victims to date has reported rates of PTSD (Table 3). A school-based study found that PTSD symptomatology increased the risk of current suicidal ideation and past suicide attempt, even after controlling for depression and gender (Mazza, 2000). In one longitudinal study of suicidal ideation and attempts, early onset (≤ age 14) PTSD was associated with lifetime suicide attempt, but no concurrent association was found (Reinherz et al., 1995). In adults, the association between PTSD and suicidal behavior in patients with a lifetime history of MDD appears to be mediated by the frequency of cluster B personality disorder comorbidity (Oquendo et al., 2005).

Psychosis. Psychotic individuals are at increased risk for both suicide and attempted suicide, but suicide does not occur frequently in psychotic

Table 4 Psychiatric risk factors for suicide in case-control studies of adolescent suicide victims (OR and 95% CI)

	Shaffer (1996)			Brent (1999)			Aggregated Risk			
	Total	Male	Female	Total	Male	Female	Total	Male	Female	
Any psychiatric disorder	22.0 (2.5–195)	5.0 (2.7–9.3)	4.3 (1.2–15.0)	4.8 (2.8–8.4)	15.6 (7.9–30.6)	11.2 (3.1–40.8)	14.2 (7.9–25.6)	8.7 (2.9–26.7)	6.9 (2.7–17.4)	9.4 (3.7–23.9)
Any mood disorder	10.2 (2.5–42.4)	11.3 (4.4–28.7)	25.2 (2.8–225)	13.0 (5.5–30.8)	9.1 (3.9–21.4)	14.2 (3.9–51.2)	8.2 (4.2–15.9)	10.0 (5.3–18.9)	16.4 (5.4–49.7)	9.8 (6.0–16.1)
Substance abuse	4.1 (1.1–14.8)	7.2 (2.6–20.2)	.5 ^a (.02–13.0)	5.8 (2.2–14.9)	11.9 (4.1–34.6)	12.2 (1.3–113)	12.7 (4.9–33.3)	9.2 (4.4–19.2)	3.1 (1.1–68.6)	7.2 (3.7–13.9)
Any anxiety disorder	–	3.2 (1.4–7.4)	.7 (2–3.3)	2.3 (1.1–4.6)	13.0 (1.7–100)	2.8 (7–11.9)	4.2 (1.5–11.5)	4.8 (1.3–17.4)	1.5 (4–5.5)	2.8 (1.6–4.9)
Conduct disorder	–	3.5 (1.6–7.8)	3.3 (3–39.1)	3.5 (1.6–7.3)	7.4 ^b (3.0–18.5)	1.4 (2–8.9)	6.1 (2.8–13.1)	4.9 (2.4–10.3)	1.9 (4–8.4)	4.6 (2.6–7.9)
Previous suicide attempt	–	34.3 (4.4–265)	37.2 ^{2*} (2.0–706)	50.6* (6.7–382)	52.8 (7.1–392)	68.3 ^a (3.6–1281)	89.3 (12.1–657)	42.7 (10.2–179)	50.4 (6.3–403)	67.4 (16.3–280)

Note: OR indicates Mantel Haenszel odds ratio; CI, confidence interval.

^a.1 = .5 added to each cell; ^bconduct/antisocial disorder.

*not estimated in original paper.

individuals until young adulthood (Allebeck, Allgulander, & Fisher, 1988; Kotila & Lonnqvist, 1989; Otto, 1972).

Eating disorders. Shaffer et al. (1996), using parent report, found a 5% prevalence of eating disorders among young female suicide victims, with no cases reported among female controls, male suicide victims, or male controls. A meta-analysis of suicide in anorexia nervosa shows average mortality rates due to suicide among 14–25-year-olds 8 times higher than expected rates of suicides in the general population (Pompili, Mancinelli, Girardi, Ruberto, & Tatarelli, 2004).

Eating disorder was associated with a significantly elevated risk of serious suicide attempt in one case-control study (OR = 14.2, 95% CI = 1.8–111.3) (Beautrais, Joyce, & Mulder, 1996b). Conversely, female suicide attempters are more likely to have abnormal eating behaviors, including eating disorders (Andrews & Lewinsohn, 1992; Borowsky et al., 2001).

Psychiatric comorbidity. Psychological autopsy studies have demonstrated that up to 70% of youth who commit suicide have multiple comorbid disorders, with risk for completed suicide increasing with the number of comorbid disorders (Brent et al., 1999; Shaffer et al., 1996). Similarly, high rates of comorbidity have been reported in studies of youth attempted suicide (Beautrais et al., 1998a; Brent et al., 1993b; Fergusson & Lynskey, 1995b; Gould et al., 1998; Lewinsohn et al., 1996; Reinherz et al., 1995). The combination of mood, disruptive, and substance abuse disorders is a particularly potent combination for youth suicide and suicidal behavior (Brent et al., 1999; Gould et al., 1998; Lewinsohn et al., 1996; Renaud et al., 1999; Shaffer et al., 1996; Shafii et al., 1988).

Suicide in the apparent absence of disorder. Several studies have investigated suicide in the absence of any mental or substance abuse disorder (Apter et al., 1993; Brent, Perper, Moritz, Baugher, & Allman, 1993c; Marttunen et al., 1998) (Table 3). Brent et al. (1993c) found that suicide victims without clear psychopathology were more likely than community controls without psychopathology to have had prior suicidal behavior, legal or disciplinary problems, and access to a loaded gun. Marttunen et al. (1998) also found that male suicide victims with no diagnosable psychiatric disorder were more likely than those with a disorder to communicate thoughts for the first time just before suicide, and to experience more disciplinary problems.

While psychiatric disorder is very common in adolescent suicides as a whole, 40% of suicide completers under the age of 16 do not appear to have a diagnosable psychiatric disorder, with a pattern of

lower intent and a greater role for the availability of lethal means (Brent et al., 1999; Groholt et al., 1998; Shaffer et al., 1996).

Physical health

Poor physical health and physical disability were associated with suicidal ideation or behavior in several studies, even after controlling for other risk factors (Dubow, Kausch, Blum, Reed, & Bush, 1989; Gartrell, Jarvis, & Derksen, 1993; Grossman, Milligan, & Deyo, 1991; Rey Gex, Narring, Ferron, & Michaud, 1998). Some studies suggest an association between suicidal behavior and specific chronic illnesses, such as diabetes and epilepsy (Brent, 1986; Goldston, Kovacs, Ho, Parrone, & Stiffler, 1994). Functional impairment due to illness or injury has also been associated with future suicide attempt in the prospective study of Lewinsohn et al. (1996).

Intercorrelated health risk behaviors

Suicidal behavior rarely occurs in isolation. Instead, it most frequently co-occurs with other health risk behaviors, such as binge eating, binge drinking, tobacco use, weapon carrying, and having unprotected sex (King et al., 2001). Common risk factors to all these difficulties are poor parent-child connection, low parental supervision, poor connection between child and school, and association with a deviant peer group (Borowsky et al., 2001; Resnick et al., 1997).

Personality and psychological factors

Personality disorder/Impulsive aggression. In most psychological autopsy studies, personality disorder was found in about one-third of suicide victims (Table 3). In one controlled study, personality disorder conveyed a 2.9-fold greater risk for suicide, with an 8.5-fold risk conveyed by cluster B (antisocial, borderline, histrionic, narcissistic) disorders after controlling for mood, substance, and conduct disorders (Brent et al., 1994a).

Impulsive aggression, defined as a tendency to react to frustration or provocation with hostility or aggression, is a psychological trait that has been shown to predispose to suicidal behavior (Apter et al., 1995; Beautrais, Joyce, & Mulder, 1999). A large proportion of child and adolescent suicide attempters exhibit assaultive and aggressive behavior independent of depression (Apter, Bleich, Plutchik, Mendelsohn, & Tyano, 1988; Brent et al., 1993a; Cohen-Sandler et al., 1982; Pfeffer, Plutchik, & Mizruchi, 1983). Impulsive aggression has been consistently implicated in the phenomenology, neurobiology, and the familial transmission of suicidal behavior (Brent, Bridge, Johnson, & Connolly, 1996a; Brent et al., 2002, 2003b; Mann, 1998; Mann, Waternaux, Haas, & Malone, 1999).

Impulsivity. Several studies reveal an association between impulsivity and adolescent suicidal behavior (Kashden, Fremouw, Callahan, & Franzen, 1993; Kingsbury, Hawton, Steinhardt, & James, 1999), although this association was attenuated after controlling for hopelessness, neuroticism, external locus of control, self-esteem, and extroversion (Beautrais et al., 1999). Many adolescent suicide attempts show relatively little planning, and prevention of suicide for the impulsive-subgroup may need to focus on restriction of lethal means (Brent, 1987a; Brent et al., 1999, 1993c; Gunnell, Murray, & Hawton, 2000).

Neuroticism. Neuroticism, a personality trait characterized by a temperamental tendency to experience a more prolonged and severe range of negative affect in response to stress, has been linked with youth suicide attempts and suicidal ideation (Beautrais et al., 1999; Benjaminsen, Krarup, & Lauritsen, 1990; Enns, Cox, & Inayatulla, 2003; Fergusson et al., 2000). Neuroticism has particularly strong discriminative power in case-control studies, is associated with familial suicide, and in one large birth cohort study predicts eventual suicide attempts, even after controlling for other significant risk factors (Beautrais et al., 1999; Fergusson et al., 2000; Roy, 2002).

Self-esteem. Lower self-esteem has been associated with current and future youth suicide attempts, but this association may attenuate after controlling for depression and hopelessness (Fergusson & Lynskey, 1995a; Lewinsohn et al., 1994; Overholser, Adams, Lehnert, & Brinkman, 1995).

Hopelessness. Hopelessness is associated with completed and attempted suicide in some community and clinical samples, but this effect is attenuated in some studies after controlling for depression (Goldston et al., 2001; Lewinsohn et al., 1994; Shaffer et al., 1996). Hopelessness has also been associated with suicidal behavior in referred samples in some (Spirito, Overholser, & Hart, 1991), but not all studies (Brent, Kolko, Allan, & Brown, 1990; De Wilde, Kienhorst, Diekstra, & Wolters, 1993).

Perfectionism. In a study of adolescent completed suicide, no association was found between perfectionism and suicide (Shaffer et al., 1996). Perfectionism, particularly the perception that others have unrealistically high expectations, has been reported to be a risk factor for youth suicide attempts (Boergers, Spirito, & Donaldson, 1998), although in one study the association was attenuated after controlling for psychopathology (Gould et al., 1998).

Sexual orientation. One psychological autopsy study has examined the association between

non-heterosexual sexual orientation and suicide, and failed to find a difference between cases and controls (Shaffer, Fisher, Hicks, Parides, & Gould, 1995), although a psychological autopsy procedure may not be sensitive enough to detect issues of sexual orientation.

Community studies have demonstrated that non-heterosexual sexual orientation and same-sex attraction are risk factors for attempted suicide. Putative factors mediating the relationship between gay, lesbian, and bisexual (GLB) orientation and suicide include higher rates of mood and substance abuse disorders, victimization, and family rejection (Borowsky et al., 2001; Fergusson, Horwood, & Beautrais, 1999; Garofalo, Wolf, Wissow, Woods, & Goodman, 1999; Remafedi, Farrow, & Deisher, 1991; Remafedi, French, Story, Resnick, & Blum, 1998). In one study, youth who reported same-sex sexual orientation were at greater risk than their peers to have attempted suicide, even after controlling for other suicide risk factors like depression, hopelessness, alcohol abuse, and recent victimization (Russell & Joyner, 2001).

Familial factors in youth suicidal behavior

Parental psychopathology. Parental psychopathology, including depression, substance abuse, and antisocial behaviors, is a risk factor for youth attempted and completed suicide (Brent, 1995; Brent et al., 1988, 1994b; de Wilde, Kienhorst, Diekstra, & Wolters, 1992; Fergusson & Lynskey, 1995a; Gould et al., 1996; Joffe et al., 1988; Pfeffer, Normandin, & Kakuma, 1994b). Some studies find that parental depression and substance abuse conveys an increased risk for suicide after controlling for psychopathology in the adolescent (Brent et al., 1994b), while others do not (Gould et al., 1996).

Family history of suicidal behavior. There is strong and convergent evidence from adoption, twin, and family studies that suicidal behavior is familial, and perhaps, genetic, and that the liability to suicidal behavior is transmitted in families independently of psychiatric disorder per se (Brent & Mann, 2005). Proband with suicide attempt showed increased risk of suicide in their family, whereas completed suicide probands showed increased risk of attempt, supporting the view that the phenotype being transmitted was a tendency to suicidal behavior, which varies in lethality (Brent & Mann, 2005).

A 2–6-fold increased rate of suicidal behavior is found in the relatives of adolescent suicide victims and suicide attempters, even after controlling for higher rates of psychopathology in relatives and offspring in cross-sectional (Agerbo, Nordentoft, & Mortensen, 2002; Borowsky et al., 2001; Brent et al., 1996a; Gould et al., 1996; Grossman et al., 1991; Johnson, Brent, Bridge, & Connolly, 1998;

Rey Gex et al., 1998), and prospective studies (Fergusson, Beautrais, & Horwood, 2003). High-risk studies comparing the offspring of mood disordered attempters to those of mood disordered non-attempters also report a 5–6-fold increase in offspring suicide attempt, independent of depression and other psychopathology in offspring (Brent et al., 2002; Lieb, Bronisch, Hofler, Schreier, & Wittchen, 2005). Greater family loading for suicidal behavior was associated with a higher risk and earlier age of onset of suicide attempt in offspring, suggesting that early-onset suicidal behavior may be particularly familial (Brent et al., 2003b). In one high-risk study, transmission of suicidal behavior from parent to child was mediated by the transmission of impulsive aggression (Brent et al., 2003b), which suggests that impulsive aggression may be a behavioral endophenotype that describes a genetic diathesis for suicidal behavior.

Family-environmental factors

Family constellation. Suicide completers are more likely than community controls to come from non-intact families of origin, although the relationship between divorce and suicidal behavior may be explained by the increased rate of psychopathology in parents whose marriages end in divorce (Brent et al., 1993e, 1994b; Gould et al., 1996; Johnson et al., 2002). Also, the relationship between suicide attempt and marital disruption may be mediated by other psychosocial risk factors such as the quality of the relationship between each of the parents, particularly the father and the child (Beautrais et al., 1996b; Fergusson et al., 2000; Groholt, Ekeberg, Wichstrom, & Haldorsen, 2000; Tousignant, Bastien, & Hamel, 1993).

Loss. Several studies have found that loss of a parent to death or divorce, or living apart from one or both biological parents is a significant risk factor for completed suicide (Agerbo et al., 2002; Brent et al., 1994b; Groholt, Ekeberg, Wichstrom, & Haldorsen, 1997; Shafii et al., 1985). Lewinsohn et al. (1996) found an association between loss of a parent prior to age 12 and multiple suicide attempts. Friends and siblings of adolescent suicide completers showed an increased risk of depression after the death, but no increased risk of suicidal behavior (Brent, Moritz, Bridge, Perper, & Canobbio, 1996b, 1996c). However, in a longer follow-up of this cohort, persistent traumatic grief was common, and associated with a 5-fold greater likelihood of suicidal ideation, after controlling for depression (Prigerson et al., 1999).

Family relationships. There is a consistent literature linking family discord with youth suicide and suicide attempts (Asarnow & Carlson, 1988; Brent et al., 1994b; Fergusson & Lynskey, 1995b; Gould

et al., 1996; Kerfoot et al., 1996; Kosky, Silburn, & Zubrick, 1990; Reinherz et al., 1995; Rey Gex et al., 1998; Taylor & Stansfeld, 1984), although in one study of suicide, this effect was attenuated after controlling for both parental and proband psychopathology (Brent et al., 1994b).

The quality of the parent-child relationship is also an important factor in suicide and suicidal behavior (Wagner, Cole, & Schwartzman, 1995). Gould et al. (1996) found that poor communication with father was a significant risk factor for suicide in older adolescents, even after adjusting for other factors. Tousignant et al. (1993) also found that a negative father-child relationship had a key and enduring role in suicidal behavior of adolescents and young adults. Lack of perceived parental support or availability is also associated with adolescent attempted suicide (Fergusson & Lynskey, 1995b; Yuen et al., 1996). Conversely, family cohesion, positive parent-child connection, spending time together, parental supervision, and high parental academic and behavior expectations were protective (Borowsky et al., 1999; Resnick et al., 1997).

Maltreatment. Physical and sexual abuse, particularly the latter, are strongly associated with attempted and completed suicide (Borowsky et al., 1999; Brent et al., 1999; Fergusson, Horwood, & Lynskey, 1996; Kosky et al., 1990; Molnar, Berkman, & Buka, 2001; Pfeffer et al., 1994a; Wagner et al., 1995). The population attributable risk (PAR) of sexual abuse for suicide attempts in adolescents in population studies has been estimated to be 16.6–19.5%, with much greater risk for suicidal behavior following more serious sexual abuse, such as intercourse (J. Brown, Cohen, Johnson, & Smailes, 1999; Fergusson et al., 1996; Johnson et al., 2002). While the main effect of sexual abuse on suicidal behavior appears to be mediated through an increased risk for psychopathology (Fergusson et al., 2000), there may be an independent effect for both risk and early age of onset of suicide attempt, even after controlling for increased risk for psychopathology and other factors (Borowsky et al., 1999; Grossman et al., 1991; Molnar et al., 2001; Rey Gex et al., 1998).

The effects of child maltreatment and its relationship to suicide are compounded by the intergenerational transmission of abuse. The familial transmission of suicidal behavior is more likely if the attempting parent had been sexually abused as a child, in part because parental history of abuse makes the child more likely to be abused, which then increases his or her risk for suicide attempt (Brent et al., 2003b). Thus, abuse is not only a risk factor for suicidal behavior for those abused as children, but also for their offspring.

'Drifting.' Youth who are disconnected from major support systems (school, work, and family) appear to

be at very high risk for suicide, particularly in the context of other risk factors that are likely to contribute to their 'drifting' status (Gould et al., 1996). Living apart from parents is a risk factor for attempted suicide, even after adjusting for other risk factors (Rey Gex et al., 1998). Adolescents on the verge of dropping out have many indicators of suicidal risk (Eggert, Thompson, Herting, & Nicholas, 1995). Furthermore, the risk of attempted suicide increases among school dropouts or after a period of absence from school (Beautrais et al., 1996b; Wunderlich, Bronisch, & Wittchen, 1998). Conversely, positive connection to school and academic achievement appears to be protective against suicidal behavior (Borowsky et al., 1999; Resnick et al., 1997).

Biological factors

The neurobiology of suicide and suicidal behavior is a well-researched area, but little work has been done in younger samples (Mann, 2003). The most consistent biological finding has been a relationship between altered central serotonin, as assessed by neuroendocrine challenge tests and cerebrospinal fluid (CSF) studies in attempters, and by receptor binding in post-mortem studies. Low CSF 5-hydroxyindoleacetic acid (5HIAA), a metabolite of serotonin, has been associated with impulsive aggression and suicidal behavior across psychiatric conditions in adults (Mann, 1998). Greenhill et al. (1995) found an association between serotonin measures and medically serious attempts within a small sample of adolescent suicide attempter inpatients with MDD. In one study of preadolescent boys, low CSF 5-HIAA was not correlated with aggression (Kruesi et al., 1990), but predicted aggression upon follow-up, after the sample had entered puberty (Kruesi et al., 1992). Altered response to fenfluramine challenge, an alternative measure of central serotonergic function, has been associated with poor home environment, aggression, and depression, but not with suicidal behavior (Birmaher et al., 1997; Pine et al., 1997). However, among adults, greater alteration in central serotonin function has been found to be most marked in attempters less than age 30 (Malone, Corbitt, Li, & Mann, 1996).

Pandey and colleagues (1997, 2004, 2002), in a series of post-mortem studies, have shown that adolescent suicide completers compared with deceased controls without disorder have increased 5-HT_{2a} binding, decreased protein kinase A (PKA) and C (PKC) activity, down regulation of CREB, and increased activity of brain-derived neurotrophic factor (BDNF) in the prefrontal cortex and hippocampus (except PKA, which was not different in hippocampus). These findings are similar to those reported for adults, which suggest involvement of the serotonin system as well as systems involved in cell signaling and signal modulation.

Zalsman and colleagues (2001) examined the allelic association of the serotonin transporter (5-HTTLPR) with suicidal behavior and related traits in a sample of Israeli suicidal inpatients, and found no significant relationship. However, patients with the *ll* genotype were significantly different than patients with the *ls* genotype on a measure of trait violence. In a prospective-longitudinal study of a New Zealand birth cohort, Caspi and colleagues (2003) found that the *s* allele of 5-HTTLPR, in the presence of stressful life events, resulted in increased rates of depression and suicidality.

Exposure to suicide

Clusters and contagion. Gould et al. (1990a) have demonstrated that a small but statistically significant number of adolescent suicide completions occur in time-space clusters, consistent with the mechanisms of contagion and imitation. These effects have been reported both for clusters of completed (Gould et al., 1990a) and attempted suicide (Gould, Petrie, Kleinman, & Wallenstein, 1994), and appear limited to adolescents and young adults (Brent et al., 1989; Gould, 2001; Gould et al., 1994; Gould, Wallenstein, Kleinman, O'Carroll, & Mercy, 1990b; Phillips & Carstensen, 1986).

Media influences. Publicity about suicide, whether through newspaper accounts, television news reports, or fictional docudramas, is followed by an increase in the rate of suicide and suicide attempt (Gould, 2001; Gould & Shaffer, 1986; Phillips & Carstensen, 1986; Schmidtke & Schaller, 2000; Stack, 2000). Factors that increase the likelihood of imitation include the amount of publicity and the notoriety of the victim (Gould, 2001; Stack, 2003). Presenting suicide in a factual light (i.e., related to mental disorder) as compared to romanticizing suicide was associated with a lower risk of imitation (Stack, 2005). There is some evidence that imitation may be method-specific (Schmidtke & Schaller, 2000).

Prospective studies of exposure. Brent et al. (1996c) found no evidence of an increased incidence of suicidal behavior in the friends exposed to the suicide of an adolescent peer, compared to unexposed community controls, despite increased risk of depression and PTSD. Similarly, Hazell and Lewin (1993) in an Australian sample found that adolescents exposed to an adolescent suicide did not show an increased rate of suicidal behavior in comparison to unexposed adolescent controls. On the other hand, Ho and colleagues (2000), in a cross-sectional study, found that peers of Chinese adolescent suicide attempters and completers had higher rates of suicidal behavior than unexposed controls, even after controlling for age, sex, and potential risk factors. Several studies have found an association

between attempted suicide and having a friend who has made a suicide attempt, although this could be accounted for by assortative friendships rather than exposure (Grossman et al., 1991; Lewinsohn et al., 1994; Rey Gex et al., 1998). However, Lewinsohn et al. (1994) found that a recent suicide attempt by a friend was a significant predictor of a future suicide attempt, even after controlling for depression and psychosocial risk factors.

Availability of lethal agents

Case-control studies. A series of case-control studies has demonstrated a clear and consistent association between firearms in the home and completed suicides, with a particularly high risk of suicide conveyed by guns in the homes of American adolescents and young adults (Brent et al., 1988, 1993f; Kellermann et al., 1992; Shah, Hoffman, Wake, & Marine, 2000; Wiebe, 2003), although these results were not replicated in New Zealand (Beautrais, Joyce, & Mulder, 1996a). If a gun is present in the home, it is highly likely to be used as the method of suicide, whereas, in the absence of a firearm in the home, this method is infrequently chosen (Brent et al., 1991, 1993f; Kellermann et al., 1992). Keeping a gun locked, unloaded, storing ammunition locked, and in a separate location are each associated with a further reduction in firearm risk (Grossman et al., 2005).

Cross-country comparative studies. A series of cross-sectional studies have shown a relationship between stricter gun control legislation and firearms availability and lower suicide rates (Killias, 1993; Krug, Dahlberg, & Powell, 1996; Sloan, Rivara, Reay, Ferris, & Kellermann, 1990). In one cross-national comparison, the overall suicide rates in two similar cities, Seattle and Vancouver, were similar but the suicide rate among 15–24-year-olds was 40% higher in Seattle, a difference accounted for almost entirely by a 10-fold excess rate of firearm-related suicide in that city (Sloan et al., 1990). This supports the view that gun availability may be particularly salient for youth suicide.

Quasi-experimental studies. Quasi-experimental studies that have examined the impact of changes in firearms legislation on suicide rates provide modest support for a role for greater restrictiveness of gun legislation in the reduction of the suicide rate, sometimes without compensatory method substitution (Cantor & Slater, 1995; Carrington & Moyer, 1994; Cummings, Grossman, Rivara, & Koepsell, 1997; Loftin, McDowall, Wiersema, & Cottey, 1991; Webster et al., 2004).

The availability of potentially lethal drugs may also increase the risk of suicide or at least increase the medical lethality of an attempt (Brent, 1987a). Legislation restricting the amount of drug available per

purchase and the use of blister packs requiring individual pills to be removed from a card with each pill in its own 'bubble' (rather than sold as loose tablets) may reduce the morbidity and mortality due to paracetamol overdose (Chan, 1996; Hawton et al., 2001, 1996). Restriction of drug content per purchase resulted in a 4-fold lower fatality from overdose in France, compared to England (Gunnell et al., 1997a). The introduction of blister packaging of paracetamol in the UK was associated with a 21% reduction in overdoses and a 64% reduction in severe overdoses (Turvill, Burroughs, & Moore, 2000).

Intervention

There is a paucity of clinical trials studying the treatment of adolescent suicidal behavior. Most treatment studies of depressed adolescents exclude suicidal adolescents and/or do not report impact of treatment on suicidal ideation and behavior. In one psychotherapy trial that included suicidal, depressed adolescents, whereas cognitive behavioral therapy was superior to family therapy and supportive therapy with regard to resolution of depressive symptomatology, there were no group differences with regard to suicidality (Brent et al., 1997). In the Treatment of Adolescent Depression Study (TADS), whereas fluoxetine was markedly superior to placebo in the treatment of depression, there were no differences in the rate of reduction of suicidal ideation, although there was a significant reduction in all groups (March et al., 2004). There was an approximately twofold increase in suicide-related adverse events in medication versus placebo in TADS (FDA 2004; March et al., 2004). The FDA recently conducted pooled analyses of short-term (4 to 16 weeks) placebo-controlled trials of nine antidepressant drugs (SSRIs and others) in children and adolescents with MDD, OCD, or other psychiatric disorders and found an increased risk of suicidality (suicidal ideation or attempt) in those receiving antidepressants (FDA 2004; March et al., 2004). While no subject in any of these studies committed suicide and very few attempted suicide, the average risk of such events on drug was 4%, twice the placebo risk of 2% (odds ratio = 1.8, 95% confidence interval = 1.1–2.8).

Harrington et al. (1998) found that home-based family therapy was not different than treatment as usual for the treatment of adolescent suicide attempters, except in the subgroup of non-depressed adolescents, in which there was a reduction in suicide attempts. Wood et al. (2001) found that a skills-based group treatment was better than treatment as usual for reduction in repetitive self-harm. Rotheram-Borus et al. (2000, 1996b) found that emergency room psychoeducation and treatment session increased compliance with a brief cognitive behavioral family therapy for adolescent suicide attempters, which in turn was related to better mental health

outcomes in mothers and daughters. One study reported that multi-systemic therapy (MST) was superior to hospitalization for prevention of suicide attempts, but nearly half of the MST group were also hospitalized, making interpretation of the findings difficult (Huey et al., 2004). One study to enhance the social network of suicidal adolescents found a small impact on suicidal ideation and mood for females, but not males (King et al., in press). One quality improvement study in adolescents with depression treated in primary care showed that collaborative care improved depression more than usual care, and showed a trend toward reducing suicidal ideation or attempts at 6-month follow-up (Asarnow et al., 2005). Other studies are either too small, or quasi-experimental, but have examined skills-based therapy, dialectical-behavior therapy (DBT), without definitive results (Donaldson, Spirito, & Esposito-Smythers, 2005; Katz, Cox, Gunasekara, & Miller, 2004; Miller, Rathus, Linehan, Wetzler, & Leigh, 1997). One school-based prevention program that taught problem-solving skills and enhanced school-child connections found that overall, there were improvements in suicide risk factors, but no difference between the experimental program and a brief suicide screening followed by case management (Eggert et al., 1995).

Clinical management

Service use. The rate of mental health treatment prior to suicide varies tremendously between studies, probably reflecting national differences in access and cost of services (Luoma, Martin, & Pearson, 2002). In two US studies, only 7–20% of adolescent suicide completers had been seen for mental health treatment in the previous 1–3 months prior to the suicide (Brent et al., 1993; Shaffer et al., 1996). Whites, females, and those with either schizophrenia or disruptive disorders were most likely to have been treated before the suicide (Marttunen et al., 1992; Shaffer et al., 1996). Slap et al. (1989) found that adolescent suicide attempters were 2.5 times more likely to depend on the emergency room for routine care than were adolescents hospitalized for acute illnesses unrelated to injuries or ingestions, even after controlling for socioeconomic status.

Recognition. In general, primary care physicians are specific but not sensitive in their detection of psychosocial difficulties (Dulcan et al., 1990). In one study of primary care physicians, most providers reported (77%) not routinely screening for adolescent suicidality and other suicide risk factors, despite having a high rate (47%) of encounters with adolescent suicide attempters in the previous year (Frankenfield et al., 2000).

Inpatient hospitalization. Hospitalization is considered a linchpin in the management of the acutely

suicidal patient (Shaffer & Pfeffer, 2001). While the hospital environment is viewed as a safe place to deal with the suicidal crisis, there are no empirical data to support the efficacy of this very costly intervention (Greenhill & Waslick, 1997; Shaffer & Pfeffer, 2001). Hospitalized patients are at particularly high risk for suicide reattempt, due to the same factors that led to their hospitalization, with the highest risk period occurring in the transition from inpatient to lesser levels of care (Appleby, Dennehy, Thomas, Faragher, & Lewis, 1999; Huey et al., 2004; Taiminen, Kallio-Soukainen, Nokso-Koivisto, Kaljonen, & Kelenius, 1998).

Transition from inpatient to less restrictive levels of care. Among adolescent suicide attempters, compliance with aftercare was best achieved when hospital staff scheduled the initial appointment with the therapist to whom the adolescent was being referred (Granboulan, Roudot-Thoraval, Lemerle, & Alvin, 2001). Education has also been found to be helpful in improving adherence (Rotheram-Borus et al., 1996a).

Because of the high suicide risk following discharge from hospital, particularly in non-adherent patients, Carter et al. (2005) studied the impact of sending postcards over a year period following discharge of suicide attempters 16 years of age or older in a randomized trial. Over the first year of follow-up, the intervention group had fewer suicide attempts, and used few hospital days.

School-based programs. Several controlled studies that have examined students' help-seeking behavior following suicide awareness programs have failed to find a positive effect, with some evidence that the students most at risk became distressed because of the intervention, and less likely to seek care (Shaffer, Garland, Vieland, Underwood, & Busner, 1991; Shaffer et al., 1990; Spirito, Overholser, Ashworth, Morgan, & Benedict-Drew, 1988; Vieland, Whittle, Garland, Hicks, & Shaffer, 1991). These findings resulted in a shift in school-based programs from 'suicide awareness' to a more generic emphasis on mental health (Kalafat & Elias, 1994). Comprehensive direct case-finding via systematic screening and subsequent clinical referral may be a more effective means of identifying suicidal youth, but the efficacy of this approach has not yet been established (Shaffer & Gould, 2000; Shaffer et al., 2004). However, it is now well established that there are no adverse effects from direct screening of students for suicidal behavior (Gould et al., 2005).

Safety plans and no harm contracts. The negotiation of the safety plan is considered one of the most critical parts of the assessment and treatment of suicidality, and involves the securing of lethal agents (e.g., firearms), a review of precipitants that led to the suicidal crisis, and brief training in emotional regulation (Brent, 1997). The no-harm contract, an

important component of safety plans, is an agreement between the adolescent, parents and clinician that should the adolescent have suicidal impulses, he/she will inform a responsible adult and/or call the clinician or emergency room, and a method for coping with suicidal urges, should they occur (Drye, Goulding, & Goulding, 1973; Rotheram-Borus & Bradley, 1990, 1991). No-harm contracts may be either verbal or written. Clinical guidelines caution against using no-harm contracts as a pre-condition to coerce adolescent patients, since it may obscure the adolescent's true suicidal risk status (Shaffer & Pfeffer, 2001).

There is virtually no empirical evidence to support the effectiveness of safety plans in general, and no-harm contracts in particular (Kelly & Knudson, 2000; Reid, 1998; Shaffer & Pfeffer, 2001; Stanford et al., 1994). The only data to support this approach is a quasi-experimental study that showed a reduction in suicide attempts among youth in a runaway shelter after the staff implemented a brief assessment and emotion regulation training for youth judged to be at risk for suicide attempts (Rotheram-Borus & Bradley, 1991).

Means restriction counseling. Despite broad acceptance of the importance of means restriction, this aspect of suicide risk management has not been subject to rigorous evaluation. Studies in emergency room settings document the low prevalence of means restriction education for suicidal patients (McManus et al., 1997; Wislar et al., 1998). While one emergency room pilot study suggests that after counseling, parents are much more likely to remove firearms from the home (Kruesi et al., 1999), studies in psychiatric and pediatric outpatient settings have not demonstrated a palpable effect of parent education (Brent, Baugher, Birmaher, Kolko, & Bridge, 2000; Grossman et al., 2000). The lack of success may be due to insisting on removal of the gun rather than securing it, not speaking directly to the gun owner, and not ascertaining the perceived risks of removing the gun (Brent & Bridge, 2003).

Model of suicidal behavior

On the basis of the extant literature, we present a developmental-transactional model of youth suicidal behavior, which has the heuristic advantage that one can theoretically identify *precursors* of suicidal behavior and use this model to develop interventions to attenuate suicide potential (Figure 1). As has been well articulated by others (Brent & Mann, 2003a; Mann et al., 1999; Shaffer & Pfeffer, 2001), suicidal behavior may arise through an interaction of two sets of vulnerabilities – major psychiatric disorder, most commonly mood disorder, and a tendency to impulsive aggression, which in turn may have

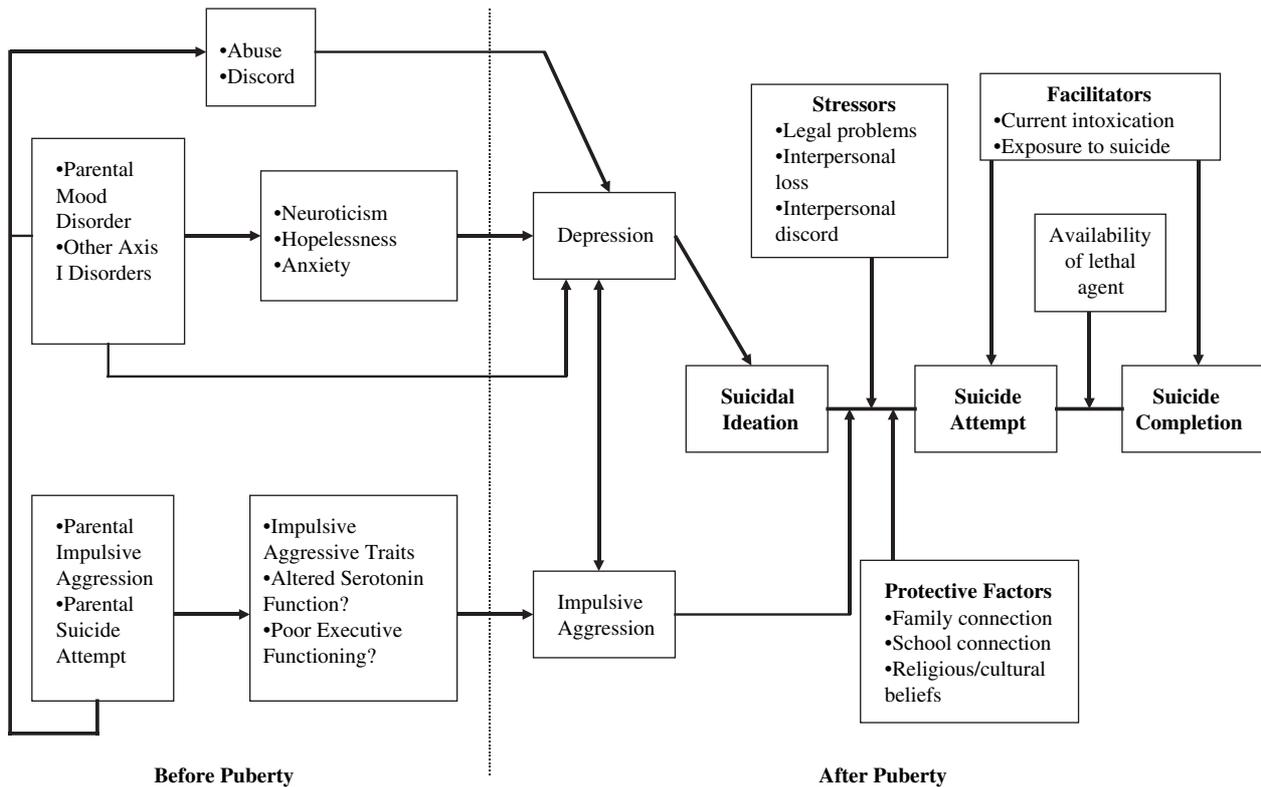


Figure 1 Developmental-transactional model of youth suicidal behavior

neurobiological correlates such as impaired executive functioning and altered serotonin metabolism in the ventral prefrontal cortex.

While each domain is presented separately, in reality, these domains are not orthogonal and exert bi-directional influence. For example, impulsive aggression in a child may increase the likelihood of depression, and conversely, early-onset depression may lead to emotion-regulation difficulties manifesting as impulsive aggression (Brent et al., 2004b; Jaffee et al., 2002; Lewinsohn, Gotlib, & Seeley, 1997).

Because so many of the factors involved in early-onset suicidal behavior are familial (either genetic or environmental), this model begins with parental risk factors, and depicts the transmission of risk factors from parent to child. Suicidal behavior is rare prior to the onset of puberty, in large part because mood disorder, one of the important components of suicidal risk, is rare prepubertally. Precursors of mood disorder that are likely to be manifested prepubertally include impulsive aggression, neurotic traits, anxiety, and cognitive distortions such as pessimism. After puberty, when mood disorder and impulsive aggression co-occur, the liability to suicidal behavior increases dramatically. While suicidal behavior can occur in the absence of either set of vulnerabilities, the co-occurrence of both sets makes suicidal behavior much more likely to ensue.

Suicidal ideation is a frequent precursor to suicide attempt, but is much more likely to ‘progress’ to

actual behavior in the presence of impulsive aggression. In addition, the co-occurrence of certain acute stressors, such as legal/disciplinary problems and interpersonal conflict or loss, may make it more likely that a suicide ideator will act on their ideation. Potential ‘facilitators’ of suicidal behavior include intoxication and exposure to suicidal behavior (Brent, 1987a; Gould et al., 1998; Lewinsohn et al., 1994). Availability of a lethal agent, such as a gun, can make the attempt more likely to result in fatality. Countering facilitators are protective factors that reduce the likelihood of onset and progress of ideation to attempt, namely a positive parent–child connection, active parental supervision, high behavioral and academic expectations, positive school–child connection, and religious and cultural beliefs against suicide (Borowsky et al., 2001; Resnick et al., 1997).

Confluence of risk factors

The mantra of suicide prevention over the past decade has been to improve the identification and treatment of psychiatric disorders. However, the single biggest risk factor for completed suicide is a previous suicide attempt, even after controlling for psychiatric disorder. Suicidal and suicide attempting patients are frequently excluded from clinical trials, making it impossible to know if treatment of psychiatric disorder will reduce risk for reattempt in the highest risk populations. Nonetheless, given that

chronicity, severity, and complexity (e.g., comorbidity) of psychiatric disorder are all related to suicidal risk, it seems likely that earlier identification and earlier symptomatic relief is an important component of the prevention and treatment of youth suicidal behavior.

Consequently, given the paucity of treatment studies that specifically target suicide attempters, such studies are indicated. There are now some promising psychosocial treatments that involve cognitive, emotion-regulation, and interpersonal approaches that should be tested in younger populations (Brown et al., 2005; Guthrie et al., 2001; Linehan, Armstrong, Suarez, Allmon, & Heard, 1991). Moreover, pharmacological approaches should also be considered, particularly for those youth with recurrent suicidal behavior, which target aggressive and emotional dysregulation such as lithium, other mood stabilizers, and atypical neuroleptics.

In light of the intercorrelation of different health risk factors, such as binge eating, binge drinking, weapon carrying, having unprotected sex, and suicidal behavior, a broader focus on interventions that target common vulnerabilities is warranted (Brent, 2004a). Correlative studies suggest that protective factors common to these health risk behaviors are parent-child connection, supervision, and expectations, and school connection (Resnick et al., 1997). Interventions that increase these protective factors may indeed be helpful in targeting young people with multiple risk behaviors.

It may be possible to identify families in whom it is highly likely that a child will become a suicide attempter, such as a child with a parent with a mood disorder and history of suicide attempt (Brent et al., 2002, 2003b, 2004b). Interventions should be developed to attenuate risk for familial transmission of suicidal behavior.

While it is important to improve our treatments in high-risk patients who seek services, one must recognize that the majority of suicide completers and attempters never come to the attention of specialty mental health care (Brent et al., 1993; Shaffer et al., 1996). Many of these young people have other health service system contacts, such as emergency rooms, juvenile detention, unemployment offices, schools, and child welfare (Gray et al., 2002; Slap et al., 1989). Better linkages to mental health and on-site delivery of services may serve to bring help to these young people.

It is also important to evaluate some of the 'tried and true' aspects of the management of suicidal youth. Can improved continuity of care reduce suicidal risk associated with discharge from hospital? Are there elements of a safety plan that are helpful or harmful? Is hospitalization, particularly involuntary commitment, likely to be of benefit? Do hotlines reach the people who need help and do they make a

difference? Do postventions in schools actually reduce the risk of contagion?

In younger adolescents, for whom completed suicide is less a function of psychopathology and intent, and more a matter of access to lethal agents, interventions to reduce access to guns and other lethal agents may reduce the burden of suicide. However, prior efforts at getting parents to remove firearms have had mixed results at best (Brent et al., 2000; Grossman et al., 2000; Kruesi et al., 1999). Therefore, further research is indicated in finding acceptable methods for getting parents to adhere to better safety practices.

Finally, further research on the genetics and neurobiology of early-onset suicidal behavior and related endophenotypes, such as impulsive aggression and their interaction with stressful life events like abuse, is needed. Neuroimaging provides the opportunity to examine correlates of poor problem-solving, emotional reactivity, and impulsivity that characterize many young suicide attempters. These studies in turn may both help to clarify the phenotypes that are most profitable to study genetically, and provide further guidance for treatment.

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Development of the adolescent brain: implications for executive function and social cognition

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Adolescence is a time of considerable development at the level of behaviour, cognition and the brain. This article reviews histological and brain imaging studies that have demonstrated specific changes in neural architecture during puberty and adolescence, outlining trajectories of grey and white matter development. The implications of brain development for executive functions and social cognition during puberty and adolescence are discussed. Changes at the level of the brain and cognition may map onto behaviours commonly associated with adolescence. Finally, possible applications for education and social policy are briefly considered. **Keywords:** Adolescence, brain development, cognition, puberty, social cognition.

Adolescence is a time characterised by immense hormonal and physical changes (Coleman & Hendry, 1990; Feldman & Elliott, 1990). This transition from childhood to adulthood is also characterised by dramatic changes in identity, self-consciousness and cognitive flexibility (Rutter & Rutter, 1993). There seems to be a qualitative shift in the nature of thinking such that adolescents are more self-aware and self-reflective than prepubescent children. Adolescents develop a capacity to hold in mind more multidimensional concepts and are thus able to think in a more strategic manner. Empirical research on cognitive and neural development during puberty and adolescence is in its initial stages. In the past few years, several pioneering experiments have investigated the development of brain and cognitive processes during this period of life.

This review begins by describing the cellular studies that first demonstrated anatomical brain developments during adolescence. It then describes how recent brain imaging techniques have supported these findings and have shed some light on the trajectories of structural brain maturation during adolescence. The following sections discuss investigations of cognitive development, in particular studies of executive functions and social cognition using behavioural and functional imaging techniques. Finally, applications for education and social policy are briefly suggested.

The first experiments on adolescent brains

Until recently, very little was known about brain development during adolescence. The notion that the brain continues to develop after childhood is relatively new. Experiments on animals, starting in the 1950s, showed that sensory regions of the brain go through sensitive periods soon after birth, during which time environmental stimulation appears to be

crucial for normal brain development and for normal perceptual development to occur (Hubel & Wiesel, 1962). These experiments suggested the human brain might be susceptible to the same sensitive periods in early development. Indeed, later experiments demonstrated sensitive periods in the first year of life for sensory capacities such as sound categorisation (Kuhl, Williams, Lacerda, & Stevens, 1992). Based on these experiments, the idea that the human brain may continue to undergo substantial change after early sensitive periods seemed unlikely.

It was not until the late 1960s and 1970s that research on post-mortem human brains revealed that some brain areas, in particular the prefrontal cortex, continue to develop well beyond early childhood. Studies carried out in the 1970s and 1980s demonstrated that the structure of the prefrontal cortex undergoes significant changes during puberty and adolescence (Huttenlocher, 1979; Huttenlocher, De Courten, Garey, & Van Der Loos, 1983; Yakovlev & Lecours, 1967).

Two main changes were revealed in the brain before and after puberty. As neurons develop, a layer of myelin is formed around their extension, or axon, from supporting glial cells. Myelin acts as an insulator and massively increases the speed of transmission (up to 100 fold) of electrical impulses from neuron to neuron. Whereas sensory and motor brain regions become fully myelinated in the first few years of life, although the volume of brain tissue remains stable, axons in the frontal cortex continue to be myelinated well into adolescence (Yakovlev & Lecours, 1967). The implication of this research is that the transmission speed of neural information in the frontal cortex should increase throughout childhood and adolescence.

The second difference in the brains of pre-pubescent children and adolescents pertains to changes

in synaptic density in the prefrontal cortex. An adult brain has about 100 billion neurons; at birth the brain has only slightly fewer neurons (Pakkenberg & Gundersen, 1997). However, during development many changes take place in the brain. Neurons grow, which accounts for some of the change, but the wiring, the intricate network of connections – or synapses – between neurons, sees the most significant change. Early in postnatal 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, called synaptogenesis, lasts up to several months, depending on the species of animal and brain region. At this point, synaptic densities in most brain regions are at their maximum. These early peaks in synaptic density are followed by a period of synaptic elimination (or pruning) in which frequently used connections are strengthened and infrequently used connections are eliminated. This experience-dependent process, which occurs over a period of years, reduces the overall synaptic density to adult levels.

These data came mainly from studies of sensory regions of animal brains. The first demonstration of synaptogenesis was in 1975, when it was found that in the cat visual system the number of synapses per neuron first increases rapidly and then gradually decreases to mature levels (Cragg, 1975). Further research carried out in rhesus monkeys (Rakic, 1995) demonstrated that synaptic densities reach maximal levels two to four months after birth, after which time pruning begins. Synaptic densities gradually decline to adult levels at around 3 years, around the time monkeys reach sexual maturity.

However, synaptogenesis and synaptic pruning in the *prefrontal cortex* have a rather different time course. Histological studies of monkey and human prefrontal cortex have shown that there is a proliferation of synapses in the subgranular layers of the prefrontal cortex during childhood and again at puberty, followed by a plateau phase and a subsequent elimination and reorganisation of prefrontal synaptic connections after puberty (Huttenlocher, 1979; Bourgeois, Goldman-Rakic, & Rakic, 1994; Woo, Pucak, Kye, Matus, & Lewis, 1997; Zecevic & Rakic, 2001). According to these data, synaptic pruning occurs throughout adolescence and results in a net decrease in synaptic density in the frontal lobes during this time. The focus of this review will be on cognitive implications of this second wave of synaptogenesis in the frontal cortex at the onset of puberty and the process of synaptic pruning that follows it after puberty.

Synaptic pruning is believed to be essential for the fine-tuning of functional networks of brain tissue, rendering the remaining synaptic circuits more efficient. Synaptic pruning is thought to underlie sound categorisation, for example. Learning one's own language initially requires categorising the sounds

that make up language. New-born babies are able to distinguish between all speech sounds. Sound organisation is determined by the sounds in a baby's environment in the first 12 months of life – by the end of their first year babies lose the ability to distinguish between sounds to which they are not exposed (see Kuhl, 2004 for review). For example, the ability to distinguish certain speech sounds depends on being exposed to those distinct sounds in early development. Before about 12 months of age babies brought up in the USA can detect the difference between certain sounds common in the Hindi language, which after 12 months they cannot distinguish (Werker, Gilbert, Humphrey, & Tees, 1981). In contrast babies brought up hearing the Hindi language at the same age become even better at hearing this distinction because they are exposed to these sounds in their language. This fine-tuning of sound categorisation is thought to rely on the pruning of synapses in sensory areas involved in processing sound. The studies on post-mortem brain development suggest that development of cognitive processes associated with the frontal lobes may well continue throughout adolescence.

Viewing the adolescent brain with MRI

Until recently, the structure of the human brain could be studied only after death. The scarcity of post-mortem child and adolescent brains meant that knowledge of the adolescent brain was extremely scanty. Nowadays, non-invasive brain imaging techniques, particularly Magnetic Resonance Imaging (MRI), can produce detailed three-dimensional images of the living human brain (see Figure 1). Since the advent of MRI, a number of brain imaging studies have provided further evidence of the ongoing maturation of the frontal cortex into adolescence and even into adulthood.

Linear increases in white matter during adolescence

In the past few years, several MRI studies have been performed to investigate the development of the structure of the brain during childhood and adolescence in humans (cf. Paus, 2005; Casey, Tottenham, Liston, & Durston, 2005). One of the most consistent findings from these MRI studies is that there is a steady increase in white matter in certain brain regions during childhood and adolescence. In one MRI study, a group of children whose average age was 9 years, and a group of adolescents whose average age was 14, were scanned (Sowell et al., 1999). This study revealed differences in the density of white and grey matter between the brains at the two age groups. The results showed a higher volume of white matter in the frontal cortex and parietal cortex in the older children than in the younger group. The younger group, by contrast, had a higher volume of

Magnetic Resonance Imaging (MRI) uses a very large magnetic field to produce high-quality three-dimensional images of brain structures without injecting radioactive tracers. A large cylindrical magnet creates a magnetic field around the person's head, and a magnetic pulse is sent through the magnetic field.

Different structures in the brain (so-called white matter and grey matter, blood vessels, fluid and bone, for example) have different magnetic properties and therefore they appear different in the MRI image. Sensors inside the scanner record the signals from the different brain structures and a computer uses the information to construct an image. Using MRI, it is possible to image both surface and deep brain structures in great anatomical detail.

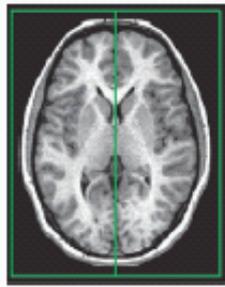


Figure 1 Magnetic Resonance Imaging (MRI)

grey matter in the same regions. Myelin appears white in MRI scans, and therefore the increase in white matter and decrease in grey matter with age was interpreted as reflecting increased axonal myelination in the frontal and parietal cortices during this time period.

The increased white matter and decreased grey matter density in the frontal and parietal cortices throughout adolescence has now been demonstrated by several studies carried out by a number of different research groups with increasingly large groups of subjects (Barnea-Goraly et al., 2005; Giedd et al., 1996, 1999a; Pfefferbaum et al., 1994; Reiss, Abrams, Singer, Ross, & Denckla, 1996; Sowell, Thompson, Tessner, Toga, 2001; Sowell et al., 2003). Different studies point to developmental changes in white matter density in different brain regions. Paus et al. (1999a) analysed the brain images of 111 children and adolescents aged between 4 and 17 years, and noted an increase in white matter specifically in the right internal capsule and left arcuate fasciculus. The left arcuate fasciculus contains white matter tracts that connect anterior speech regions (Broca's area) and posterior language regions (Wernicke's area). Thus the increase in white matter in this region was interpreted as reflecting increased connections between the speech regions. The corpus callosum, the dense mass of fibres that connects the two hemispheres of the brain, has also been found to undergo region-specific growth during adolescence and up until the mid-twenties (Barnea-

Goraly et al., 2005; Giedd et al., 1999b; Pujol, Vendrell, Junque, Marti, & Josep, 1993).

While structural neuroimaging studies diverge in terms of the precise brain regions in which white matter density increases have been found, they generally agree on the pattern of white matter change. Most studies point to a steady, more-or-less linear increase in white matter with age (see Figure 2) (Barnea-Goraly et al., 2005; Giedd et al., 1999a; Paus et al., 1999a; Paus, Evans, & Rapoport, 1999b; Reiss et al., 1996; Pfefferbaum et al., 1994) and in light of histological studies, this has consistently been interpreted as reflecting continued axonal myelination during childhood and adolescence.

Non-linear decreases in grey matter during adolescence

While the increase in white matter in certain brain regions seems to be linear across all brain areas, the changes in grey matter density appear to follow a region-specific, non-linear pattern. In other words, while white matter development follows a steady, progressive course, grey matter development is at certain stages progressive and at other times regressive. As the following studies have shown, its pattern of development in certain brain regions follows an inverted-U shape.

Giedd et al. (1999a) performed a longitudinal MRI study on 145 healthy boys and girls ranging in age from about 4 to 22 years. At least one scan was

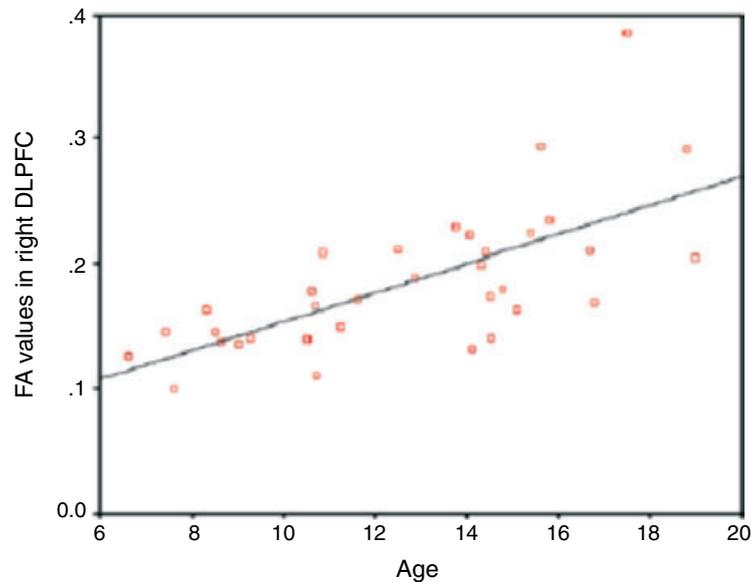


Figure 2 Linear development of white matter with increasing age in the right DLPFC. The graph shows the correlation between age and amount of white matter (as indicated by fractional anisotropy value (FA) determined by structural features of tissue such as fibre density and diameter) (Barnea-Goraly et al., 2005)

obtained from each of 145 subjects (89 were male). Scans were acquired at two-year intervals for 65 of these subjects who had at least two scans, 30 who had at least three scans, two who had at least four scans and one who had five scans. Individual growth patterns revealed heterochronous grey matter development during adolescence. Changes in the frontal and parietal regions were similarly pronounced. The volume of grey matter in the frontal lobe increased during pre-adolescence with a peak occurring at around 12 years for males and 11 years for females. This was followed by a decline during post-adolescence. Similarly, parietal-lobe grey matter volume increased during the pre-adolescent stage to a peak at around 12 years for males and 10 years for females, and this was followed by a decline during post-adolescence. Grey matter development in the temporal lobes was also non-linear, but the peak was reached later at about 17 years. In the occipital lobes, grey matter development had a linear course (Giedd et al., 1999a).

A further MRI study of 35 normally developing children (7–11 years), adolescents (12–16 years) and young adults (23–30 years) demonstrated a sharp acceleration in the loss of grey matter between childhood and adolescence in the dorsal prefrontal cortex and the parietal cortex (Sowell et al., 2001). In the frontal lobes, the decrease in grey matter density was even more pronounced between adolescence and adulthood. In addition, an inverse relationship between dorsal prefrontal cortex growth and grey matter density was found to exist between childhood and adolescence. The regions exhibiting the most robust decrease in grey matter density also exhibited the most robust post-pubescent increase in white matter density in the dorsal prefrontal cortex.

In a longitudinal study of participants aged between 4 and 21, Gogtay et al. (2004) scanned 13 children every two years for 8 to 10 years. In terms of grey matter density, they found that sensory and motor brain regions matured first. This was followed by the remainder of the cortex maturing from the back to the front (parietal cortex to frontal cortex). The loss of grey matter occurred last in the superior temporal cortex. The authors noted that phylogenetically older brain areas matured earlier than newer ones.

A similar pattern of development was found in a longitudinal study of children aged from 3 to 15 years (Thompson et al., 2000). In this experiment, high spatial resolution maps of the brain's growth patterns were obtained using tensor mapping, with the same subject being scanned across time spans of up to four years. In the older group (11 to 15 years) a localised grey matter decrease in the frontal cortex was observed. This study provided further evidence of a sharp acceleration of grey matter density loss between childhood and adolescence in dorsal frontal cortex.

Thus, rather than a simple linear change in grey matter with age, studies suggest perturbation in grey matter density development that more or less coincides with the onset of puberty. At puberty, grey matter volume in the frontal lobe reaches a peak, followed by a plateau after puberty and then a decline throughout adolescence continuing until early adulthood. The MRI results demonstrating a non-linear decrease in grey matter in various brain regions throughout adolescence have been interpreted in two ways. First, it is likely that axonal myelination results in an increase in white matter and a simultaneous decrease in grey matter as viewed by MRI. A second, additional explanation is that the grey matter changes reflect the synaptic reorganisation that

occurs at the onset of and after puberty (Huttenlocher, 1979; Bourgeois et al., 1994). Thus, the increase in grey matter apparent at the onset of puberty (Giedd et al., 1999a) might reflect a wave of synapse proliferation at this time.

The gradual decrease in grey matter density that occurs after puberty in certain brain regions has been attributed to post-pubescent synaptic pruning (Giedd et al., 1999a; Sowell et al., 2001; Gogtay et al., 2004). In other words, the increase in grey matter at puberty reflects a sudden increase in the number of synapses. At some point after puberty, there is a process of refinement such that these excess synapses are eliminated (Huttenlocher, 1979), resulting in a steady decline in grey matter density.

Gender differences in development of brain structure

A cross-sectional MRI study of 46 children and adults (mean age 11) revealed significant differences in grey and white matter between girls and boys, particularly in the inferior frontal gyrus (IFG) (Blanton et al., 2004). A significant age-related increase in white matter volume in the left IFG was found in boys but no significant volumetric changes were found in girls in any frontal regions (see Figure 3). Furthermore, even after correcting for total cerebral volume, boys had significantly greater grey matter volume in the IFG relative to girls. The authors speculated that these structural differences may arise from the difference in steroid levels between girls and boys during pubertal maturation. It was suggested that the effect of inhibition of synaptic pruning from testosterone may account for greater volume in boys than in girls. On the other hand, it was proposed that greater hemispheric specialisation (cf. Shaywitz

et al., 1995) among boys may account for the gender differences in structure. So far, structural studies are not in full agreement with regard to gender differences. For example, in a longitudinal study, it was found that boys had 10% greater total cortical grey matter volume than girls, but that developmental trajectories of grey and white matter volume were not significantly different (Giedd et al., 1999a). Larger longitudinal studies will help to overcome variability in frontal cortex anatomy, to discern gender differences more clearly.

Brain changes continue after adolescence

Recent MRI studies indicate that the time at which the brain reaches maturity may be much later than the end of adolescence. One such study of participants aged between 7 and 30 revealed that the loss of grey matter in the frontal cortex accelerated during adulthood between the early 20s and up to the age of 30 (Sowell et al., 2001).

A further MRI study by the same group involved scanning 176 individuals between 7 and 87 years (Sowell et al., 2003). The results revealed a reduction in grey matter density in the dorsal prefrontal, parietal and temporal cortices, which was accompanied by an increase in white matter. The pattern of grey matter changes was non-linear during the period of adolescence. Although the decrease in grey matter was most dramatic from childhood to young adulthood, the data revealed that white matter volume continued to increase well beyond this stage and even up to the age of 60. The non-linear decrease in grey matter was concomitant with a linear increase in white matter, consistent with earlier MRI data and with post-mortem studies.

To summarise, while early cellular studies in animals suggested that morphological changes in the brain more or less cease early on in infancy, *in vivo* MRI studies coupled with post-mortem cellular studies of human brains have revealed an extended period of development, in particular in the frontal and parietal cortices. Taken together, the studies provide consistent evidence for the dynamic nature of the adolescent brain with respect to maturational changes of grey and white matter. The main changes that have been observed are a non-linear reduction in frontal grey matter density and a simultaneous linear increase in white matter.

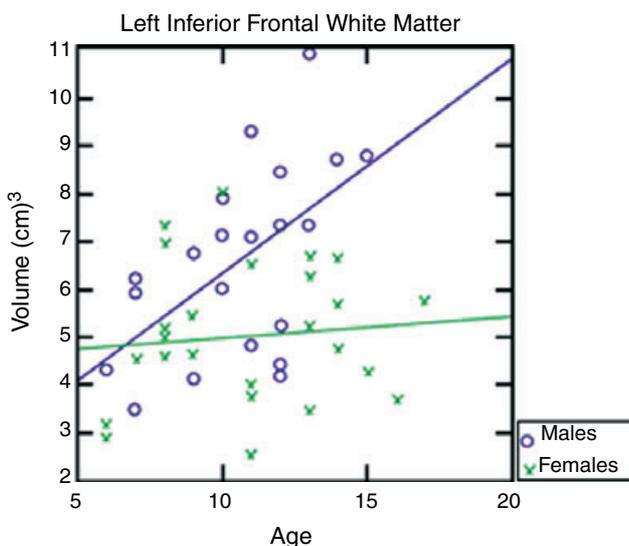


Figure 3 Relationship between age and volume of white matter in the IFG for males and females. A significant linear relationship was found between age and IFG white matter for males (Blanton et al., 2004)

Changes in behaviour and cognition after puberty

Two of the brain regions that have consistently been shown to undergo continued development during adolescence are the prefrontal cortex and the parietal cortex. Given the continued structural changes in these brain regions during adolescence, it might be

expected that cognitive abilities that rely on the functioning of these regions and their complex interconnectivity with other regions should also change during this time period. Most studies to date have investigated cognitive abilities subserved by the frontal lobes, in particular executive function.

Development of executive function

The term *executive function* is used to describe the capacity that allows us to control and coordinate our thoughts and behaviour (Luria, 1966; Shallice, 1982). These skills include selective attention, decision-making, voluntary response inhibition and working memory. Each of these executive functions has a role in cognitive control, for example filtering out unimportant information, holding in mind a plan to carry out in the future and inhibiting impulses. Much work on human and monkey brain and behaviour has associated these strategic behaviour skills with the frontal lobes. Lesion studies (Goldman-Rakic, 1987; Rakic, Bourgeois, & Goldman-Rakic, 1994; Shallice, 1982) and functional imaging experiments (e.g. Casey et al., 1997; Rubia et al., 2001; Rubia, Smith, Brammer, & Taylor, 2003) suggest that such skills rely heavily on the frontal lobes. Since MRI studies have demonstrated changes in frontal cortex during adolescence, executive function abilities might be expected to improve during this time. For example, selective attention, decision-making and response inhibition skills, along with the ability to carry out multiple tasks at once, might improve during adolescence. While many studies have investigated the development of executive function skills in early and late childhood (e.g. Paus, 1989; Paus, Babenko, & Radil, 1990; Casey et al., 1997; Brocki & Bohlin, 2004; Klenberg, Korkman, & Lahti-Nuutila, 2001), only a handful of studies have investigated the changes in executive function skills during adolescence.

Behavioural studies show that performance of adolescents on tasks including inhibitory control (Leon-Carrion, Garcia-Orza, & Perez-Santamaria, 2004; Luna, Garver, Urban, Lazar, & Sweeney, 2004a), processing speed (Luna et al., 2004a), working memory and decision-making (Luciana, Conklin, Cooper, & Yarger, 2005; Hooper, Luciana, Conklin, & Yarger, 2004) continues to develop during adolescence. Luna et al., for example, showed that performance on an oculomotor task undergoes a large improvement from childhood to adolescence, followed by a plateau between adolescence and early adulthood (Luna et al., 2004a). Another study investigating performance on a variety of executive function tasks between the ages of 11 and 17 demonstrated a *linear* improvement in performance on some tasks but not others (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Improvement during adolescence was observed on tasks of selective attention, working memory and problem solving,

whereas strategic behaviour, as tested by the Tower of London task (Shallice, 1982), seemed to have been formed earlier in childhood. Different aspects of executive function, therefore, may have different developmental trajectories. These studies used a systems neuroscience approach to cognition to speculate that the developments in performance are linked to the pruning and myelination processes occurring during adolescence in the frontal cortex.

Prospective memory is the ability to hold in mind an intention to carry out an action at a future time (Ellis, 1996), for example remembering to make a phone call at specific future time. Prospective memory is associated with frontal lobe activity (Burgess, Veitch, Costello, & Shallice, 2000) and has been shown to develop through childhood as we develop our future-oriented thought and action (Ellis & Kvavilashvili, 2000). Multitasking is believed to be a test of prospective memory as it requires participants to remember to perform a number of different tasks, mirroring everyday life. In a recent study of the development of prospective memory from childhood to adulthood, a multitask paradigm was used to test children aged between 6 and 14 and adults (MacKinlay, Charman, & Karmiloff-Smith, 2003). Participants were scored for both efficiency and the strategies used to carry out the task effectively. A significant improvement in both the efficiency and quality of strategies was found between the ages of 6 and 10. However, between the ages of 10 and 14, there was no significant change in performance. The adult group (mean age 25), on the other hand, significantly outperformed the children. The authors therefore suggested that prospective memory continues to develop during adolescence, in line with the notion of frontal maturation in the brain. It is possible that the lack of improvement in performance between the 10- and 14-year-olds was related to their pubertal status.

A *non-linear* pattern of development was found in a recent behavioural study that used a match-to-sample task (McGivern, Andersen, Byrd, Mutter, & Reilly, 2002). In this task, volunteers were shown pictures of faces showing particular emotional expressions (happy, sad, angry), or words describing those emotions ('Happy,' 'Sad,' 'Angry'), and were asked to specify, as quickly as possible, the emotion presented in the face or word. In a third condition, volunteers were shown both a face and a word, and had to decide whether the facial expression matched the emotional word. The rationale behind the design of the task was that the face/word condition places high demands on frontal lobe circuitry, since it requires working memory and decision-making. The task was given to a large group of children aged 10 to 17 years and a group of young adults aged 18 to 22 years.

The results revealed that at the age of puberty onset, at 11–12 years, there was a decline in performance in the matching face and word condition

compared with the younger group of children. A 10–20% increase in reaction time on the match-to-sample task occurred at the onset of puberty in the 10–11-year-old group of girls and in the 11–12-year-old group of boys, compared to the previous year group of each sex (age 9–10 and 10–11 in girls and boys, respectively) (see Figure 4). The results suggest that there is a dip in performance on this kind of task at the onset of puberty. After puberty, from age 13–14, performance improved until it returned to the pre-pubescent level by the age of about 16–17 years.

The researchers linked this pubertal dip in performance to the proliferation of synapses that occurs at the onset of puberty. Based on these psychophysical results and in the context of structural MRI studies discussed above, it was suggested that until pruning occurs after puberty, synaptic connections in the frontal cortex generate a low signal to noise ratio due to an excess of synapses, which renders the cognitive performance less efficient. Therefore, the sudden proliferation of synapses that occurs at puberty results in a perturbation of cognitive performance. Only later, after puberty, are the excess synapses pruned into specialised, efficient networks which may explain the post-pubescent improvement on this task (McGivern et al., 2002).

Development of social cognition

In addition to executive functions, there is evidence that the prefrontal cortex is involved in several other high-level cognitive capacities, including self-

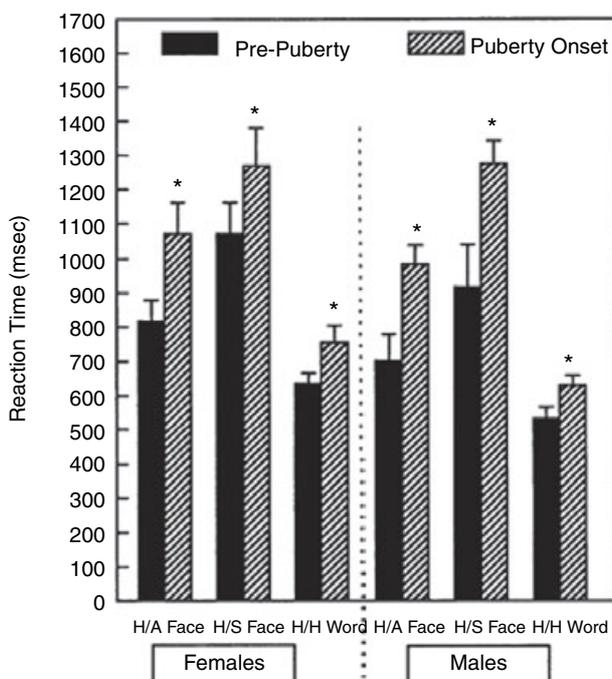


Figure 4 Significant difference in reaction times for emotional match-to-sample task between the year preceding and the average age of puberty onset (McGivern et al., 2002)

awareness (Ochsner, 2004) and theory of mind (Frith & Frith, 2003), that is the ability to understand other minds by attributing mental states such as beliefs, desires and intentions to other people (Frith, 2001). In addition to neural development, there are major changes in hormones at puberty. While it is impossible to tease apart all of the important influences on the social and emotional behaviour of adolescents, significant neural development and hormonal changes are likely to influence social cognition. Social cognition, then, may also be expected to change during this time period. In addition, the interaction may be two-way. During this time, what is perceived as important in the social world around us also changes and leaves its imprint on the pruning process. Accumulating new social experiences, for example, when entering a new school, may influence the development of social cognitive processes. So far, very few studies have addressed the effect of puberty and adolescence on social cognitive abilities.

Perspective taking

Perspective taking is the ability to take on the viewpoint of another person. The ability to take another's perspective is crucial for successful social communication. In order to reason about others, and understand what they think, feel or believe, it is necessary to step into their 'mental shoes' and take their perspective. Perspective taking is related to first-order theory of mind in that it involves surmising what another person is thinking or feeling. Perspective taking includes awareness of one's own subjective mental states ('first-person perspective', or 1PP) and the ability to ascribe mental states to another person ('third-person perspective' or 3PP). Despite much theoretical debate, there is little consensus about the mechanisms underlying perspective taking. One prevalent view is that we understand others by mentally simulating their actions and thoughts (Harris, 1995; Gallese & Goldman, 1998). In support of this 'simulation theory', a growing body of evidence from neurophysiological studies has demonstrated that common brain areas are activated both when we execute an action and when we observe another person perform the same action (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996a; Rizzolatti et al., 1996b; Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Decety et al., 1997; Buccino et al., 2001). Common brain areas are also activated when subjects perceive a visual scene or answer a conceptual question from their own, first-person, perspective and from another person's perspective. Functional neuroimaging studies have revealed that the parietal and frontal cortices are associated with making the distinction between 1PP and 3PP at the motor (Ruby & Decety, 2001), visuo-spatial, (Vogeley et al., 2004), conceptual (Ruby & Decety, 2003) and emotional (Ruby & Decety, 2004) level. These studies

suggest that the organisation of motor, social and affective knowledge is not distinct, but that they are intertwined with one another. It is proposed that 'mirror neurons' that fire when an agent both performs an action or observes another person performing the action provide a basis for integrating perceptual, motor and social functions (see Rizzolatti, Fogassi, & Gallese, 2001 for review). In each of these contexts, superior frontal and right inferior parietal cortex are activated to a greater extent during 3PP than during 1PP. Several neuroimaging studies have implicated the inferior parietal cortex in the distinction between the self and others at the sensorimotor level (Blakemore, Wolpert, & Frith, 1998; Farrer & Frith, 2002; Ruby & Decety, 2001).

So far there has been a lack of attention to the development of social cognition during adolescence. In a recent study, the development of perspective taking was investigated before, during and after puberty (Choudhury, Blakemore, & Charman, 2005). These data suggest that development of social perspective taking undergoes a perturbation during puberty in parallel with the discontinuous processes of brain maturation. As described earlier, histological studies of human prefrontal cortex have shown that there is a proliferation of synapses in the prefrontal cortex during childhood, followed by a plateau phase and a subsequent elimination and reorganisation of prefrontal synaptic connections after puberty (Huttenlocher, 1979). Cognitive processes that depend on the prefrontal cortex might undergo a perturbation at puberty due to the synaptic reorganisation that occurs at this time.

To our knowledge, this is the first study that has investigated the development of perspective taking during adolescence. Further experiments on the development of other social cognitive processes are being carried out in our laboratory and other research centres and may shed more light on the effect of puberty and adolescence on social cognition.

With regard to face processing, differential developmental trajectories for recognition of the six Ekman emotion faces were reported from a behavioural study of 484 children and adolescents aged between 6 and 16 years (Lawrence et al., submitted). The computerised task required participants to match an emotional label (happy, sad, angry, fearful, disgusted and surprised) to images of facial expressions, and responses were recorded. Accuracy data indicated that emotion recognition abilities develop during adolescence. In particular, recognition of fear and disgust showed the greatest linear improvements with age, while there was no improvement in the ability to recognise sad and angry expressions in this age range. In addition, pubertal status, independent of age, affected emotion recognition. Recognition of fear, disgust and anger improved with pubertal development, as determined by the Pubertal Development Scale (Peterson et al., 1988). Given that the processing of facial expressions is associ-

ated with prefrontal activity (Sprengelmeyer, Rausch, Eysel, & Przuntek, 1998), it was proposed that the structural developments in the adolescent prefrontal cortex and the concomitant change in the hormonal environment differentially affect neural circuits involved in particular aspects of emotion recognition.

These recent findings are in line with previous studies that also showed an interruption at puberty in the developmental course of face recognition (Carey, Diamond, & Woods, 1980; Diamond, Carey, & Back, 1983; Flin, 1983). In one study, for example, the percentage of correct responses in a behavioural face recognition task improved by over 20% between the ages of 6 and 10 (Carey et al., 1980). However, this was followed by a decline around the age of puberty. Between ages 10 and 12, participants showed a drop in accuracy of over 10%. Performance on the task recovered again from the age of approximately 14 up to 16. Similarly, in another study, face encoding was found to be worse in pubescent girls compared with pre- and post-pubescent girls matched for age (Diamond et al., 1983). The authors suggested that the decline in performance was a result of hormonal changes at puberty that may impact directly on cognitive performance or alternatively that adolescents' new form of self-awareness and awareness of other people in response to their bodily changes at puberty may lead to a reorganisation of face representation.

Further investigation of the influence of puberty on brain development and cognition would, however, benefit from objective measures of pubertal development. Currently, if they measure puberty at all, researchers tend to rely on self-ratings, parent reports or the judgements of teachers in schools. Investigators consistently report the difficulties met in ascertaining the level of pubertal development in adolescence, even using these methods. Not only do parents and teachers often consider them to be inappropriate to administer in schools, where much cognitive testing for such studies takes place, but they are also crude indices of pubertal status. It may be worth working with endocrinologists to investigate alternative reliable methods, such as using saliva swabs to test hormone levels.

Viewing the adolescent brain in action with fMRI

Functional MRI (fMRI) provides us with a safe, non-invasive tool to study interactions between brain and behaviour (see Figure 5). fMRI has been used only in a handful of studies investigating the neural bases of cognitive development using tasks designed to tap specifically into prefrontal cortex function, in particular executive function tasks.

For example, through fMRI studies, the development of response inhibition, and the neural structures supporting it, have been well studied. A popular paradigm for studying inhibition is the Go/

Functional MRI (fMRI). In the past 15 years, techniques have been developed that enable scientists to use MRI to image the brain at work. This is known as functional MRI or fMRI. When neurons become active they require a supply of oxygen to be carried to them in the blood. It is this oxygen carried in the blood that the fMRI scanner detects because oxygen has magnetic properties. fMRI measures the amount of oxygenated blood that is sent to particular regions in the brain. This information is used to make ‘films’ of changes in brain activity as volunteers see or hear certain stimuli and do other things, like answer questions or press buttons.

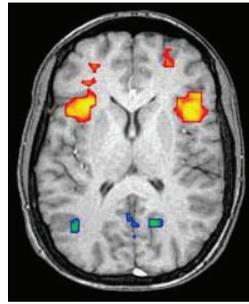


Figure 5 Functional MRI (fMRI)

No-Go task, which involves inhibiting a response when a certain stimulus is shown. In one fMRI study that employed a version of this task, a group of children (7–12 years old) and young adults (21–24 years old) were presented with a series of alphabetic letters and were required to press a button upon seeing each one, except when the letter X appeared (Casey et al., 1997). Volunteers were instructed to refrain from pressing any buttons if they saw the letter ‘X’ – the No-Go stimulus. This task requires executive action: the command to inhibit a habitual response.

The results showed that in both children and adults, several regions in the frontal cortex, including the anterior cingulate, orbitofrontal cortex and inferior and middle frontal gyri, were activated during the task that required inhibiting the normal response. While the location of activation was essentially the same for both age groups, there was a significantly higher volume of prefrontal activation in children than in adults, specifically in the dorsolateral prefrontal cortex and extending into the cingulate. By contrast, adults showed more activity in the ventral region of the prefrontal cortex. Thus the activation in the dorsolateral prefrontal cortex could be negatively correlated with behavioural performance (as interpreted from error rates), as distinct from the orbitofrontal cortex whose activation increased with improvement in behavioural performance. In line with this pattern, those subjects who performed best (that is, those who had lowest error rates) and had the greatest orbitofrontal activation also had the least dorsolateral prefrontal activation.

The greater and more diffuse activity in the dorsal region of the prefrontal cortex in children suggests

that there is a heavier dependence on this region in children compared with in adults. The researchers suggested that during adolescence, the network recruited for this task is modified until adulthood, at which stage activation of a smaller, more focal region of the prefrontal cortex is used to perform the same task.

To substantiate speculations about brain activation during inhibition during the transition between childhood and adulthood, the study was replicated with a wider age range of participants (Tamm, Menon, & Reiss, 2002). In the second study, the same Go/No-Go task was used but participants included children as well as adolescents – this time, subjects ranged in age from 8 to 20 years old. While there was no difference in accuracy on the task with age, reaction times to inhibit responses successfully significantly decreased with age. fMRI data revealed age-related increases in activation in the left inferior frontal gyrus extending to the orbitofrontal cortex and, consistent with Casey et al.’s results, age-related decreases in activation in both the left superior and middle frontal gyrus extending to the cingulate. These results demonstrated a dissociation between prefrontal areas in the development of inhibitory control and a negative correlation between age and brain activation.

This pattern of age-dependent activation has been corroborated by fMRI studies of generativity. Word generation tasks, for example, have been extensively used in experimental and clinical studies and are consistently linked to prefrontal cortex activation and are therefore useful to study development of generativity in adolescence (Brown et al., 2005; Gaillard et al., 2000). A study using a verbal fluency

task required children (average age 11 years) and adults (average age 29 years) to generate different words starting with the same letter as quickly as possible in the scanner (Gaillard et al., 2000). The results of this study revealed that children performed worse on the task and had on average 60% greater activation in the left inferior frontal cortex and the dorsolateral prefrontal cortex than did adults.

Thus, reaction times and imaging data together suggest that in children, an immature stage of the brain where excess synapses, possibly as a result of a burst of proliferation, accounts for the poorer performance and extensive and less efficient frontal activation. A pruned and more myelinated adult brain could explain the faster reaction times and focal activation of the frontal cortex, the area associated with generativity (Frith, Friston, Liddle, & Frackowiak, 1991) and the inhibitory response (Konishi et al., 1999). The Go/No-Go task requires multiple executive functions including working memory and inhibition albeit at a relatively low level. One possibility is that extensive activation in children is a compensatory strategy used while the brain is less efficient in integrating executive functions.

Adolescents are renowned for engaging in risky behaviour. A recent neuroimaging study suggests that differences in brain activation in mesolimbic circuitry during incentive-driven behaviour between adolescents and adults might account for this (Bjork et al., 2004). A group of 12 adolescents and 12 young adults were scanned while they carried out a task that involved anticipating the opportunity for both monetary gains and losses and the notification of their outcomes. Compared to adults, adolescents showed reduced recruitment of the right ventral striatum and right amygdala while anticipating responses for gains. Activation patterns during monetary gain notification did not differ between groups. This suggested lower activation for motivational but not consummatory components of reward-directed behaviour. To explain risky behaviour commonly associated with adolescence, the authors postulated that adolescents are driven to seek more extreme incentives to compensate for low recruitment of motivational brain circuitry.

Anecdotally, adolescents are known to be poor at decision-making, especially when risk is involved. In an fMRI study that investigated the neural mechanisms that might account for differences between adolescents and adults in decision-making, participants were presented with one-line scenarios (e.g. 'Swimming with sharks') and were asked to indicate via a button press whether they thought this was a 'good idea' or a 'not good idea' (Baird, Fugelsang, & Bennett, 2005). There was a significant group by stimulus interaction, such that adolescents took significantly longer than adults on the 'not good idea' scenarios relative to the 'good idea' scenarios. Furthermore, adults showed greater activation in the

insula and right fusiform face area compared to adolescents, during the 'not good' ideas. On the other hand, adolescents showed greater activation in the dorsolateral prefrontal cortex (DLPFC) during the 'not good' ideas and there was a significant correlation between DLPFC activation and reaction time. It was proposed that when confronted with a risky scenario, adults' relatively efficient responses were driven by mental images of possible outcomes and the visceral response to those images, in line with the somatic marker hypothesis (Damasio, 1996). However, adolescents relied more on reasoning capacities and therefore activated the DLPFC, hence the relatively effortful responses compared to adults.

Neural plasticity of the developing brain may underpin different propensities for learning new skills, such as problem solving, at different stages of the life cycle. For example, sensitive periods for learning phonemes of one's mother tongue occur in the first six months of life (Kuhl et al., 1992) and the ability to learn a second language declines with age (Hakuta, Bialystok, & Wiley, 2003). Logical reasoning required to solve mathematical problems activates both parietal and frontal cortex in both adolescents and adults. An fMRI study that required subjects to solve algebraic equations before and after a practice period demonstrated differential activation patterns after four days of learning in adolescents and adults (Luna, 2004b; Qin et al., 2004). Both adolescents and adults showed an increase in prefrontal, parietal and motor activation while solving the equations. Both groups also demonstrated a reduction in prefrontal areas after practice. However, adolescents, as distinct from adults, additionally demonstrated a reduction in parietal regions after the practice period. The authors proposed that the parietal cortex represents an 'imaginal' component necessary for this sort of abstract reasoning task. They proposed that after the learning period, the adolescents are less reliant on this area than the adults. However, the directions of cause and effect remain ambiguous. It is unclear whether the adolescents' decrease in parietal activation with practice was a result of an immature parietal cortex and hence a higher relative dependence on the prefrontal cortex. Alternatively, more localised parietal activation in adolescents might indicate an advantage among adolescents for this sort of task; that is, adolescents depend less heavily on more specialised parietal circuitry, compared to adults. Further functional imaging studies combined with behavioural analysis will clarify the significance of focal versus diffuse brain activation patterns for the propensity to learn.

Although several developmental studies emphasise the decrease in frontal activity with age, in others, activity in this and other regions has been found to increase with age. Using a visuo-spatial working memory task, Kwon, Reiss, and Menon (2002) found that performance gradually improved with age

between 7 and 22 years. Age-related changes were found in several brain regions including the dorso-lateral prefrontal cortex and the posterior parietal cortex bilaterally (see Figure 6). Similarly, Rubia et al. (2001) reported increased activation in various frontal and parietal regions on a task of response inhibition. Using the Stroop colour-word interference paradigm, which involves inhibition of inappropriate responses, Adleman et al. (2002) observed age-related increases in activity in a left frontal-parietal network of areas. They found no evidence of decreased activity with age.

Confounding effects of task performance

One remaining issue is the confounding effect of task performance differences in fMRI studies. If one group's task performance is worse than that of the other group, then any difference in brain activity between the two groups is difficult to interpret. It might cause the difference in task performance, or it might be an effect of these differences. Future studies should attempt to match task performance between groups to avoid this interpretation problem.

Development of social cognition in the brain

Recognition of facial expressions of emotion is one area of social cognition that has been investigated during adolescence (see Herba & Phillips, 2004). Much of the literature has focused on early development of facial recognition (Nelson, 1987). Relatively little is known about the continued development of emotion processing during adolescence. The amygdala has consistently been associated with emotion processing (Dolan, 2002; Phillips, Drevets, Rauch, & Lane, 2003). An fMRI study of the role of the amyg-

dala in normal adolescents involved scanning 12 adolescent participants (Baird et al., 1999). They found significant amygdalar activation in response to the perception of fearful facial expressions. A similar fMRI study investigated the neural processing of other facial expressions (happiness and sadness) in a group of 12 adolescent subjects (aged 13–17 years). The perception of happy faces compared with neutral faces was associated with significant bilateral amygdalar activation in adolescents (Yang, Menon, Reid, Gotlib, & Reiss, 2003). Neither of these studies contained an adult or a younger child group, so comparisons before and after puberty of the neural processing of facial emotion could not be made. Furthermore, there was no exploration of how age affects emotion expression processing. Thomas et al. (2001) addressed some of these issues by studying amygdala activation to fearful facial expressions in two groups: a group of children (mean age 11 years) and adults. Adults demonstrated greater amygdala activation to fearful facial expressions, whereas children showed greater amygdala activation to neutral faces. The authors argued that the children might have detected the neutral faces as more ambiguous than the fearful facial expressions, with resulting increases in amygdala activation in response to the neutral faces.

Killgore, Oki, and Yurgelun-Todd (2001) studied developmental changes in neural responses to fearful faces in children and adolescents. Results indicated sex-differences in amygdala development: although the left amygdala responded to fearful facial expressions in all children, left amygdala activity decreased over the adolescent period in females but not in males. Females also demonstrated greater activation of the dorsolateral prefrontal cortex over this period, whereas males

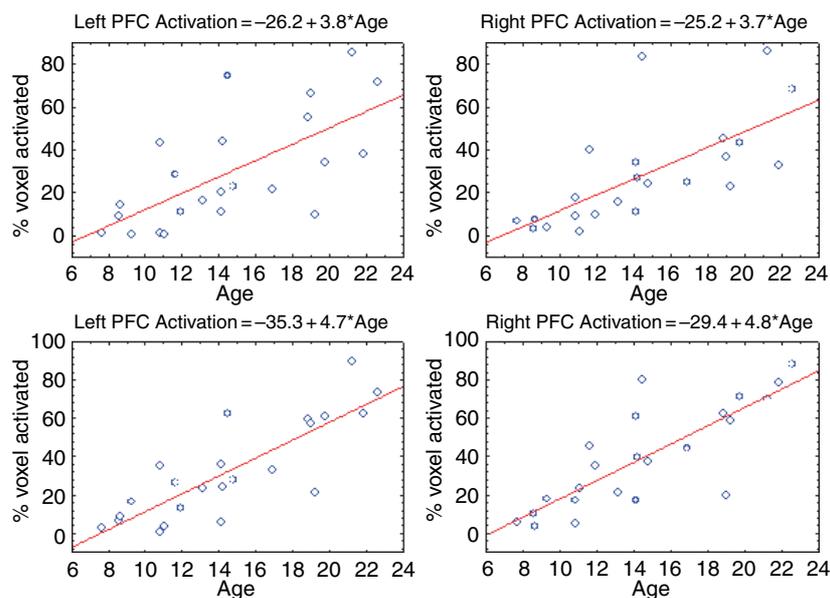


Figure 6 Increasing activation in left and right prefrontal cortex and posterior parietal cortex during working memory task (Kwon et al., 2002)

demonstrated the opposite pattern. The authors interpreted these findings as evidence for an association between cerebral maturation and increased regulation of emotional behaviour; the latter mediated by prefrontal cortical systems. It is possible that the pattern of decreased amygdala and increased dorsolateral prefrontal activation in girls with increasing age reflects an increased ability to contextualise and regulate emotional experiences *per se*.

In a recent study a group of adolescents (aged 7 to 17) and a group of adults (aged 25–36) viewed faces showing certain emotional expressions. While viewing faces with fearful emotional expressions, adolescents exhibited greater activation than adults of the amygdala, orbitofrontal cortex and anterior cingulate (see Figure 7) (Monk et al., 2003). When subjects were asked to switch their attention between a salient emotional property of the face, like thinking about how afraid it makes them feel, and a non-emotional property, such as how wide the nose is, adults, but not adolescents, selectively engaged and disengaged the orbitofrontal cortex. These fMRI results suggest that both the brain's emotion processing and cognitive appraisal systems develop during adolescence. The authors interpret these results in the context of their Social Information Processing Network model (cf. Nelson, Leibenluft, McClure, & Pine, 2005).

Implications for teenagers

An interesting speculation based on the results of the studies discussed in this review is that puberty represents a period of synaptic reorganisation and as a consequence the brain might be more sensitive to experiential input at this period of time in the realm of executive function and social cognition. This sensitive period might be akin to the sensitive periods of brain development that are evident in the early sensory system. Much like sound categorisation during language acquisition (see above), experience with executive functions and certain social cognitive skills might be much more difficult to incorporate into brain networks once they are established after puberty. This notion is purely speculative and further research, preferably with input by multiple disciplines including educational researchers, cognitive scientists and neuroscientists, may shed light on this.

Research into the cognitive implications of continued brain maturation beyond childhood may be relevant to the social development and educational attainment of adolescents. Further studies are necessary to reach a consensus about how axonal myelination and synaptic proliferation and pruning impact on social, emotional, linguistic, mathematical and creative development. In other words, which skills undergo perturbation, which undergo sensitive periods for enhancement and how does the quality of

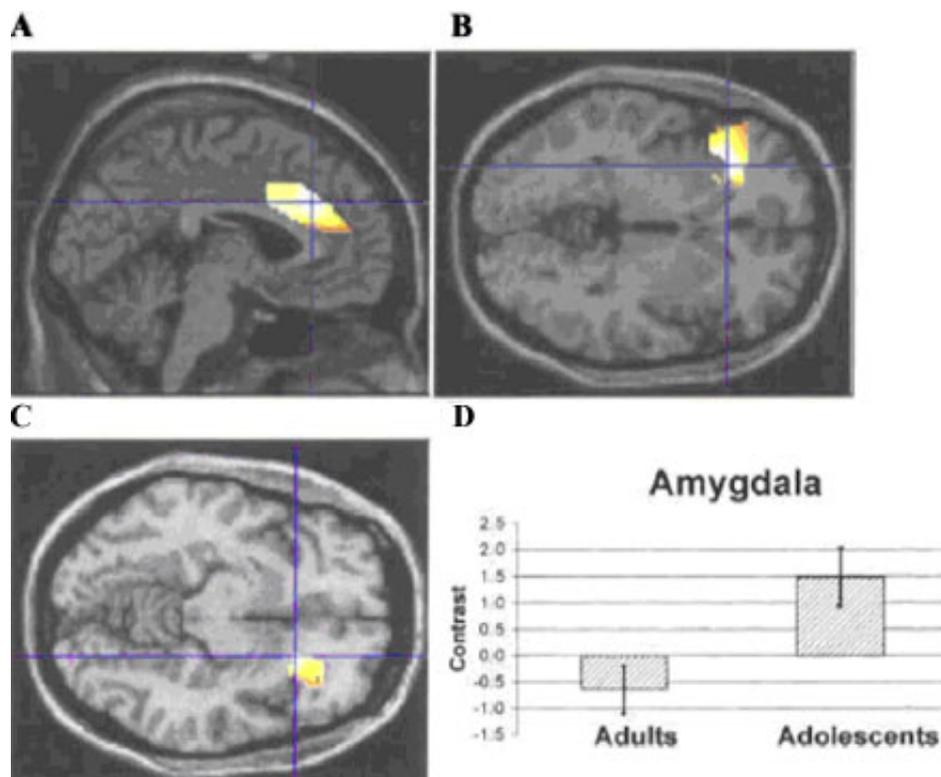


Figure 7 Activation patterns in adolescents relative to adults when passively viewing fearful impact to neutral faces. (A–D) Activation in the ACC, left OFC, right OFC, and amygdala, respectively. Crosshairs indicate cluster maxima (Monk et al., 2003)

the environment interact with brain changes in the development of cognition? Longitudinal studies of the effect of early deprivation on the cognitive development of Romanian adoptees in the UK have begun to investigate this question (O'Connor & Rutter, 2000). Whether greater emphasis on social and emotional cognitive development would be beneficial during adolescence is unknown but research will provide insights into potential intervention schemes in secondary schools, for example for remediation programmes or anti-social behaviour.

Research in psychology and cognitive neuroscience can also contribute to the debate about juvenile crime, for instance on the current use of Anti-Social Behaviour Orders (ASBOs) in the UK. ASBOs are civil orders which can be imposed against anyone aged 10 or over who is deemed to have acted in a manner which 'causes harassment, alarm or distress' to anyone, and which, if breached, become criminal offences. A dialogue between psychologists and parliamentarians would be useful to shape future legislative procedures concerning adolescent social behaviour. Current theoretical and philosophical underpinnings of criminal law are grounded in the principle of autonomy: individuals are regarded as rational autonomous human beings who can 'choose' their actions and are therefore held responsible by criminal law. This framework of the law is borrowed from philosophy rather than psychology. Drawing on recent experimental evidence from cellular, behavioural and brain imaging studies, neuroscientists and psychologists can evaluate the efficacy of ASBOs. Firstly, they can investigate the role of brain development in causing problem behaviour among adolescents. Secondly, given that the brain is still developing, psychologists can explore the long-term psychological effects of receiving an ASBO on the adolescent. Finally, neuroscience may offer insights into alternatives to current punitive methods. It may, for example, be worth allocating more resources to educational and rehabilitation programmes designed to take into account the natural developmental changes in adolescent psychology.

Conclusion

The study of the development of executive function and social cognition beyond childhood is a new but rapidly evolving field with applications for medical diagnosis, education and social policy. The finding that changes in brain structure continue into adolescence and early adulthood challenged accepted views and has given rise to a recent spate of investigations into the way cognition might change as a consequence. In this paper, we have focused on research in developmental cognitive neuroscience, but a richer account of changes in adolescent learning, and strategic and social behaviour requires a multi-disciplinary approach that recognises the complex

interactions between genetics, brain structure, physiology and chemistry and the environment. Studying the development of adolescent cognition using complementary in vivo methods that exploit the advantages of each – such as combining fMRI with electroencephalography (EEG) or diffusion tensor imaging (DTI) – within a theoretical framework that regards motor, affective, social and perceptual functions as intertwined promises to further inform our understanding of typical and atypical adolescent behaviour.

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