

The set-shifting profiles of anorexia nervosa and autism spectrum disorder using the Wisconsin Card Sorting Test: a systematic review and meta-analysis

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Difficulties in set-shifting are commonly reported in both autism spectrum disorder (ASD) and anorexia nervosa (AN) populations. Despite this, it is not known whether this cognitive profile persists across different ages, or whether the profiles seen in ASD and AN are comparable. This systematic review and meta-analyses aimed to compare the set-shifting profiles, as measured by the Wisconsin Card Sorting Test (WCST) in adults and younger people with either ASD or AN, relative to healthy controls (HCs) and to statistically compare performance on the WCST between ASD and AN. In all, 24 studies on ASD and 22 studies on AN were identified. In ASD, there were significant differences between the clinical group and HCs, with the ASD group making significantly more perseverative errors, indicating greater difficulty in set-shifting [pooled effect size of $d=0.67$, 95% confidence interval (CI) 0.53–0.81, $p \leq 0.001$]. This effect was consistent across the age span. For AN studies, there was a significant difference between adults with AN and HCs ($d=0.52$, 95% CI 0.36–0.68, $p \leq 0.001$) but a non-significant effect in child studies ($d=0.25$, 95% CI -0.05 to 0.55, $z=1.66$, $p=0.096$). Meta-regression indicated no effect of diagnosis (AN or ASD) on performance in adult studies but there was a non-significant trend ($p=0.053$) towards children with ASD performing worse than children with AN. While difficulties with set-shifting appear to be stable in ASD, there may be differences between children and adults with AN, which warrant further investigation.

Received 7 July 2015; Revised 9 February 2016; Accepted 16 February 2016

Key words: Anorexia nervosa, autism spectrum disorder, meta-analyses, set-shifting, Wisconsin Card Sorting Test.

Introduction

A growing body of literature indicates a link between anorexia nervosa (AN) and autism spectrum disorder (ASD). A systematic review of the prevalence of ASD in AN reported a mean rate of 23% (Huke *et al.* 2013); however, six of the included studies came from the same Swedish community sample and this line of research is ongoing (Nielsen *et al.* 2015). There are also similarities in cognitive style between AN and ASD (Gillberg *et al.* 2010; Oldershaw *et al.* 2011; Courty *et al.* 2013; Tchanturia *et al.* 2013a) reported in the literature. Although elevated levels of autistic traits have consistently been found within AN populations (Baron-Cohen *et al.* 2013; Tchanturia *et al.* 2013b; Huke *et al.* 2014; Rhind *et al.* 2014; Westwood *et al.* 2016) it is not known whether the

presence of these traits represents a shared, underlying mechanism (Zucker *et al.* 2007; Odent, 2010; Allely, 2013) or whether individuals with AN come to resemble those with ASD due to the chronic, starved state associated with the disorder (Pellicano & Hiller, 2013; Treasure, 2013). Direct comparison of the seemingly shared traits, as well as systematic exploration of these traits across stages of illness, e.g. childhood and adulthood, will be essential to understanding the extent to which these traits may be shared mechanisms in both AN and ASD.

Interest in the potential relationship between AN and ASD has led to examination of cognitive traits, believed to underpin ASD in AN. While some traits associated with ASD, such as emotional theory of mind, have been found to reduce in recovered AN groups (Oldershaw *et al.* 2010), other traits including difficulties with set-shifting, or flexible thinking, appear to persist after weight gain (Tchanturia *et al.* 2004; Gillberg *et al.* 2010; Danner *et al.* 2012; Lindner *et al.* 2014). Recent reports suggest that set-shifting inefficiencies are present in children with AN who have had a relatively short duration of illness (Lang

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et al. 2015a) and relatives with AN (Holliday *et al.* 2005; Roberts *et al.* 2010; Lang *et al.* 2015b). Conversely, fasting in healthy controls (HCs) has been found to reduce set-shifting test performance, suggesting that starvation may exacerbate underlying difficulties in this domain (Bolton *et al.* 2014; Pender *et al.* 2014). Thus, despite evidence of cognitive similarity between AN and ASD, the extent and nature of this likeness remain unclear. Exploring differences in the set-shifting profiles of children and adults with AN would speak to debates of whether neurocognitive traits such as set-shifting underlie the eating disorder or whether these cognitive traits are more related to eating disorder pathology such as starvation.

Differences in set-shifting have been observed between children and adults with AN. A systematic review of set-shifting ability, comparing adults with AN with HCs identified five papers employing the Wisconsin Card Sorting Test (WCST) (Heaton *et al.* 1993), a widely used measure of set-shifting, with a meta-analysis reporting a significant small effect size ($d = 0.36$; Roberts *et al.* 2007). A further meta-analysis of studies in children and adolescents with AN (Lang *et al.* 2014), however, found a non-significant pooled effect size ($d = 0.20$). A more recent study comparing children and adolescents with AN with HCs using a larger sample size (AN = 41, HC = 43) found that young people with AN made significantly more perseverative errors than HCs ($d = 0.49$; Lang *et al.* 2015a), suggesting that this cognitive profile is present early on in the disorder before the effects of starvation become prominent. A meta-analysis by Wu *et al.* (2014) included a range of neuropsychological tasks assessing set-shifting, rather than just the WCST. This revealed a medium effect size for inefficient set-shifting in restrictive AN ($g = -0.51$) but no significant effect size for binge/purge AN. Although the meta-analysis by Wu *et al.* (2014) did include studies with children and adolescents, the results did not differentiate between age groups.

Within the ASD literature, five reviews have attempted to synthesize the literature on cognitive flexibility (Hill, 2004; Kenworthy *et al.* 2008; Sanders *et al.* 2008; Geurts *et al.* 2009; Leung & Zakzanis, 2014). Studies using the WCST have consistently shown difficulties with set-shifting which are stable over time (Hill, 2004); however, this review did not differentiate between studies with adult or child participants and no quantitative synthesis was attempted. A further review (Kenworthy *et al.* 2008) reports that whilst several studies of cognitive flexibility in children and adults with ASD have demonstrated difficulties relative to HCs, the evidence is inconclusive with two of nine studies using the WCST, one with adults and one with children, producing unclear results. A

recent meta-analysis (Leung & Zakzanis, 2014) comparing neuropsychological performance between patients with ASD and HCs on number of perseverative errors on the computerized WCST, which again pooled both child and adult studies, reported a medium mean effect size ($d = 0.68$). A review of the WCST in ASD (Landry & Al-Taie, 2016) provided effect sizes for four different WCST outputs including perseveration. In this review, age was found to be negatively correlated with perseveration, the opposite of what has been observed in the AN literature. To our knowledge, however, no reviews have directly compared the set-shifting profiles of children and adults with ASD using the WCST, although, generally, results do suggest that difficulties in set-shifting may be more stable across different age groups, than in AN studies.

Despite the set-shifting difficulties found in people with AN seeming to resemble those of ASD, the cognitive profiles of these two disorders have rarely been directly compared. Oldershaw *et al.* (2011) statistically compared the neuropsychological profile of currently ill AN patients with published data of individuals with ASD on the WCST and found the two groups to be statistically similar. To our knowledge, this is the only study directly comparing the profiles of the two groups and thus further work is needed to confirm whether the set-shifting profile seen in AN truly resembles that of ASD. Furthermore, the Oldershaw *et al.* (2011) study only included adult patients. Exploring differences in the set-shifting profiles of children and adults with AN would speak to debates of whether neurocognitive traits such as set-shifting underlie the disorder. Since the publication of the study of Oldershaw *et al.* (2011), additional studies have been published in both AN and ASD, as demonstrated by the review presented here. As these studies are cross-sectional and not longitudinal, inferences on the aetiology of ASD and AN cannot be made but statistically comparing the severity of set-shifting difficulties will aid in the comparison of the neuropsychological profiles of the two disorders.

Difficulties with set-shifting have been implicated in several other psychiatric disorders including schizophrenia (Pantelis *et al.* 1999); major depression (Austin *et al.* 1999) and obsessive-compulsive disorder (Leopold & Backenstrass, 2015), suggesting that this could be a general risk factor for the development of mental disorder, rather than a trait, specific to either AN or ASD. However, evidence of deviant set-shifting in these disorders is less consistent than in AN and ASD, for example, due to the heterogeneous nature of the disorders. As specific attention has been paid to the shared behavioural traits and intermediate phenotypes in ASD and AN (Treasure, 2013), determining

both the severity and stability of set-shifting difficulties in the two disorders through meta-analysis is a necessary step to exploring shared underlying mechanisms.

If it is the case that both children and adults with ASD display inefficiencies in set-shifting, it would add evidence to suggest that this trait is stable across the trajectory of the disorder. AN studies have tended to find less difficulty with set-shifting in children than in adults but this finding is difficult to interpret as it may reflect type II errors due to small sample sizes in child studies, with the exception of one study (Lang *et al.* 2015a). It is therefore unknown whether older and younger people with AN show similar cognitive profiles. The present review aims to use sufficiently powered analysis using pooled previous samples to summarize the literature on the use of the WCST as a measure of set-shifting in both ASD and AN populations and to determine: (a) whether individuals with either ASD or AN have difficulties with set-shifting; and (b) whether the severity of these difficulties is comparable in the two disorders in both child and adult populations. This will move us closer to understanding whether the difficulties in set-shifting are stable over the course of AN and will be a necessary but not sufficient step in understanding the relationship between AN and ASD.

Method

The meta-analyses were conducted according to the 'PRISMA' (preferred reporting items for systematic reviews and meta-analysis) statement (Moher *et al.* 2009). The quality of each study was assessed using the Clinical Appraisal Skills Programme checklist for case-control studies (Critical Appraisal Skills Programme, 2013). The tool consists of 11 questions, which yield a mixture of 'yes', 'no' and more qualitative answers. In order to calculate an overall quality rating, several questions were split into subquestions and a score of 1 was awarded for every 'yes' answered, with a maximum possible score of 16. The quality rating for each study is shown in Tables 1 and 2.

Eligibility criteria

Studies using the WCST and reporting the number or percentage of perseverative errors with a clinical population of either ASD or AN and HCs were included in the review. Due to the heterogeneous nature of ASD and the broadening diagnostic criteria of both ASD and AN in the Diagnostic and Statistical Manual of Mental Disorders, 5th edition (DSM-V; American Psychiatric Association, 2013), all variants of the two disorders were included.

Information sources and search

The electronic databases Scopus, PsycINFO, PubMed and Web of Science were searched up to and including January 2016. Search terms included anorexia nervosa OR autism AND set-shifting, Wisconsin, executive function OR cognitive flexibility. Limits included English-language, peer-reviewed articles. Reference lists of eligible papers were also screened, as were existing systematic reviews related of set-shifting in either ASD or AN (Roberts *et al.* 2007; Lang *et al.* 2014; Tchanturia, 2015; Landry & Al-Taie, 2016).

Selection

The first and principal authors (H.W., K.T.) identified potential titles and screened the abstracts for relevance. Full texts were then retrieved and read to determine eligibility by H.W. Texts deemed eligible were then further screened by K.T. and any papers that did not meet inclusion criteria were excluded. Reasons for exclusion included: the WCST was not used; perseverative errors were not reported; the WCST had been adapted for use with a particular population or there was no HC group; recovered AN cases were also excluded.

Data collection and items

The data items collected from each eligible study were: diagnosis; number of participants; mean age of participants; WCST version; percentage of female participants; how HCs were matched to clinical samples; how co-morbidities were controlled for; diagnostic tools; participant intelligent quotient (IQ); country where the study was conducted; and source of participant recruitment. For AN studies, body mass index (BMI) and illness duration were also extracted. In addition to demographic and experimental paradigm data, the means and standard deviations of perseverative errors on the WCST were used within the meta-analysis.

Risk of bias in individual studies

The risk of bias in individual studies was assessed by considering how methodology would make an impact on effect size in each study, for example, by attending to how HCs were matched to clinical samples, how the WCST was administered and how participants were recruited.

Summary measure

The principal summary measure used for analysis from all studies was the difference in means and standard deviations of perseverative errors or percentage of

Table 1. Demographic information for AN studies

Author/date	Group	<i>n</i>	Mean age, years (s.d.)	Mean BMI, kg/m ² (s.d.)	Mean illness duration, years (s.d.)	Mean IQ (s.d.)	HCs matched by	WCST version	% Female AN	% Female HC	Recruited from	Diagnostic tool	Quality score	
Adult studies														
Abbate-Daga <i>et al.</i> (2011)	AN-R	30	24.1 (6.7)	15.6 (1.6)	5.2 (4.2)		Age	Paper version	100	100	ED service, mixed treatment	SCID	13	
	HC	30	24.7 (2.6)	21(2.2)										
Abbate-Daga <i>et al.</i> (2014)	AN	94	24.7 (7.3)	15.2 (2.0)	7.1 (6.6)		Race	128 cards, paper version	100	100	ED service, mixed treatment	SCID	11	
	HC	59	25.1 (3.2)	20.6 (2.0)										
Aloi <i>et al.</i> (2015)	AN-R	45	22.8 (5.6)	15.5 (1.4)				Italian version	100		ED service	SCID	13	
	HC	45	25.6 (3.5)	20.2 (1.6)										
Fagundo <i>et al.</i> (2012)	AN	35	28.1 (8.2)	17.2 (1.4)				128 cards	100		ED service	SCID	13	
	HC	137	24.8 (7.0)	21.5 (2.7)										
Fassino <i>et al.</i> (2002)	AN-R	20	23.8 (6.6)	15.2 (2.2)			Gender	Nelson's version, 48 cards	100	100	ED service	SCID	13	
	HC	20	23.1 (2.9)	20.6 (1.7)										
Galimberti <i>et al.</i> (2013)	AN	29	24.1 (6.8)	16.2 (4.0)	6 (5.1)		Gender	Computerized	100	100	High school, university	Psychiatric hospital	DSM-IV-TR	13
	HC	29	28.6 (11.9)											
Giel <i>et al.</i> (2012)	AN	15	23.9 (5.7)	15.8 (1.9)		103.0 (1.0) ^a	Age, gender, education	Computerized	100	100	ED service, mixed treatment	SCID	15	
	HC	35	30.2 (10.9)	22.0 (1.9)										
Goddard <i>et al.</i> (2014)	AN	29	26.2 (8.2)	17.7 (2.2)				Computerized	0	0	ED service, mixed treatment	EDE	15	
	HC	42	26.4 (7.2)	23.2 (2.5)										
Harrison <i>et al.</i> (2012)	AN	50	27.1 (9.3)	15.4 (1.8)	9.2 (9.8)			Computerized	100	100	ED service, mixed treatment	DSM-V	16	
	HC	89	28.5 (9.9)	21.6 (1.9)										
Koba <i>et al.</i> (2002)	AN	11									University			
Nakazato <i>et al.</i> (2010)	HC	7			10 (10.6)		Age	Computerized, 4th edition	100	100	ED service, mixed treatment	DSM-IV	13	
	AN	27	27.7 (10.6)	15.4 (1.9)										

Ohrmann <i>et al.</i> (2004)	HC	28	26.9 (5.8)	22.3 (2.5)	5.5 (5.2)		Age, gender	Modified WCST	100	100	Local community	SCID	11
	AN	11	22.7 (3.8)	15.2 (1.2)							Psychiatric in-patient service		
Pignatti & Bernasconi (2013)	HC	11	27.5 (6.3)	21.3 (2.1)			Age, education	Italian version	100	100	ED service	DSM-IV-TR	11
	AN	23	29.1 (7.4)	16.0 (2.0)									
Sato <i>et al.</i> (2013)	HC	20	27.8 (7.0)	21.6 (1.4)	3.6 (3.7)	97.8 (13.7)	Age, IQ	Computerized 128 trials	100	100	ED service, mixed treatment	DSM-IV-TR	15
	AN	15	23 (7.0)	14.6 (1.5)									
Steinglass <i>et al.</i> (2006)	HC	15	22 (3.0)	20.6 (1.2)	10.8 (5.8)	104.9 (11.3)	Gender	Computerized, 4th edition	100	100	ED research clinic	SCID	10
	AN	15	25.6 (6.0)	19 (1.0)							109.8 (12.1)		
Tchanturia <i>et al.</i> (2012)	HC	11	24 (3.1)	22.1 (1.8)			Age	Computerized, 4th edition	100	100	ED service, mixed treatment	DSM-IV	12
	AN	171	25.4 (8.2)	15.2 (1.9)							115.5 (6.6)		
Thompson (1993)	HC	199	27.7 (8.8)	21.9 (1.9)		115.8	Age, education, IQ, class, location		100	100	ED out-patient	DSM-III-R	12
	AN	10	25.8								119.7		
Van Autreve <i>et al.</i> (2013)	HC	10	23.2				Gender	Computerized, 4th edition	100	100	Local community ED service, mixed treatment	DSM-IV	12
	AN-R	31	26 (12.0)	14.4 (2.0)							University		
Child/adolescent studies	AN-BP	20	20 (4.0)	16.4 (1.1)									
	HC	26	19.0 (2.0)	20.9 (1.8)									
Andres-Perpina <i>et al.</i> (2011)	AN	37	15.4 (1.5)	15.3 (1.4)	13.2 (10.7) ^b		Age		94.6	90.2	Psychiatric hospital	DSM-IV-TR	12
Fitzpatrick <i>et al.</i> (2012)	HC	41	15.4 (1.5)			119.5 (14.5)		Computerized, 4th edition	100	100	Local school ED in-patient	DSM-IV	12
	AN	32	14.9 (1.9)	78.1 (6.6) ^b									
Lang <i>et al.</i> (2015a)	HC	22	15.4 (1.9)	105.7 (12.8) ^b		119.5 (11.0)	Gender, age	Computerized, 4th edition	100	100	Local community ED service, mixed treatment	SCID, DSM-V	15
	AN	41	15.1 (1.8)	16.2 (1.5)							107.1 (13.8)		
McAnarney <i>et al.</i> (2011)	AN-R	24	16.3 (1.2)	16.7 (1.3)		111.6 (10.7)	Age, SES, IQ, ethnicity	Computerized	100	100	DSM-IV	9	

Table 1 (cont.)

Author/date	Group	n	Mean age, years (s.d.)	Mean BMI, kg/m ² (s.d.)	Mean illness duration, years (s.d.)	Mean IQ (s.d.)	HCs matched by	WCST version	% Female AN	% Female HC	Recruited from	Diagnostic tool	Quality score
	HC	37	15.9 (1.5)	22.3 (3.7)		113.1 (10.2)							

AN, Anorexia nervosa; s.d., standard deviation; BMI, body mass index; IQ, intelligence quotient; HC, healthy control; WCST, Wisconsin Card Sorting Test; AN-R, anorexia nervosa, restrictive subtype; ED, eating disorder; SCID, Structured Clinical Interview for DSM Disorders; DSM, Diagnostic and Statistical Manual of Mental Disorders; EDE, Eating Disorder Examination; AN-BP, anorexia nervosa binge-purge subtype; SES, socio-economic status.

^a Verbal IQ.

^b Measured in months.

perseverative errors between the clinical sample (ASD or AN) and HCs on the WCST. Standardized mean scores were used within the analysis to account for the variation in version of the WCST used in the studies. The WCST involves sorting cards into one of four categories according to one of three sorting rules: colour, shape or number. Once a card has been sorted, the participant is given feedback as to whether they sorted the card according to the correct rule. The paradigm yields a number of different outputs which can be analysed including perseverative errors, when the participant continues to sort cards according to a previous rule (Lezak, 1995). The WCST is a widely used measure of general executive function (Heaton *et al.* 1993; Greve *et al.* 2005). The WCST is assumed to consist of three factors: perseveration, failure to maintain set and idiosyncratic sorting (Greve *et al.* 1998). An increased number of perseverative errors has been associated with frontal lobe dysfunction (Milner, 1963; Nelson, 1976) and, as a robust measure of conceptual flexibility, was therefore the main focus for this review.

Only studies using the WCST, rather than other set-shifting paradigms, were included because this is a widely used measure across a wide range of disorders, believed to reliably assess cognitive flexibility (Holmén *et al.* 2012). There is less variability in terms of test properties (64- or 128-card version, computerized or pen-paper) compared with other paradigms such as the trail-making test (Atkinson & Ryan, 2008). Unlike other paradigms, the WCST also provides numerous different outputs, including perseveration, the most relevant measure in relation to set-shifting. It is widely used in both AN and ASD research allowing for direct comparison between these groups. The WCST is also considered to be a purer measure of set-shifting, compared with other paradigms which may tap into other cognitive domains (Steinglass *et al.* 2006).

Synthesis of data

Synthesis of results for meta-analysis meant that only studies reporting mean scores of perseverative errors were included in the analysis. Therefore, studies which reported standardized rather than raw scores or presented results visually were not included. The reasons studies were excluded are presented in Fig. 1. The meta-analyses were performed by pooling the standardized effect sizes of each study using a random-effects model. Random-effects models assume that as well as within-group variability caused by sampling variability of scores, mean effect size is also caused by differences between studies (Borenstein *et al.* 2009). If the between-study heterogeneity is present, the random-effects model results in estimates

Table 2. Demographic information for ASD studies

Author/date	Group	n	Mean age, years (s.d.)	Mean IQ (s.d.)	HCs matched by	WCST version	% Female ASD	% Female HC	Recruited from	Diagnostic tool	Quality score
Adult studies											
Ambery <i>et al.</i> (2006)	AS	27	37.6 (14.6)		VIQ and PIQ	128 cards	18.5	20	Specialist assessment service	ICD-10, ADI, ADOS	13
	HC	20	33.5 (12.0)								
Eack <i>et al.</i> (2013)	ASD	43	24.9 (5.8)				12	33	Out-patient service	ADOS	14
	HC	24	26.3 (5.5)								
Goldstein <i>et al.</i> (2001)	HFA	103	18.2 (10.1)		FIQ and VIQ	128 cards	13.6	10.7		ADI, ADOS	12
	HC	103	19.0 (10.1)								
Griebling <i>et al.</i> (2010)	HFA	38	17.9 (10.0)		FIQ, PIQ and VIQ		5.3	4.2	University recruitment programme	ADI, ADOS, clinical description	10
	HC	40	18.6 (9)								
Hill & Bird (2006)	AS	22	31.1 (13.1)		Age, gender, general ability	Nelson's version	22.3	36.4	Support groups	APA criteria	11
	HC	22	33.5 (14.5)								
Lopez <i>et al.</i> (2005)	AS	17	29				17.6	35.3		ADI, ADOS, GARS	10
	HC	17	29								
Maes <i>et al.</i> (2011)	ASD	17	45.2 (13.1)			Computerized	23.5	21.1	University medical centre		13
	HC	19	38.4 (14.8)								
Rumsey (1985)	AS	9	27 (7)		Highest level of education	128 cards	0	0	University Nationwide register	DSM-III	11
	HC	10	28 (5)								
Sumiyoshi <i>et al.</i> (2011)	ASD	22	24.5 (4.0)		Age	Computerized 64 cards	13.6	26.7	Out-patient service	DSM-IV, AQ, CARS	13
	HC	15	29.7 (6.4)								
Yasuda <i>et al.</i> (2014)	ASD	33	26.1 (11.5)		Age, gender, education, FIQ, PIQ, VIQ	Keio version, 48 cards	39.4	39.4	Out-patient and in-patient services	DSM-IV-TR, ADI-R, PARS, AQ-J	13
	HC	33	26.8 (9.9)								

Table 2 (cont.)

Author/date	Group	<i>n</i>	Mean age, years (s.d.)	Mean IQ (s.d.)	HCs matched by	WCST version	% Female ASD	% Female HC	Recruited from	Diagnostic tool	Quality score
Adolescent/adult studies											
Minshew <i>et al.</i> (1992)	AS	15	21.1 (8.0)	95.7 (13.6)	Age, FIQ, gender and race		0	0		ADI, ADOS	10
	HC	15	21.3 (8.3)	96.5 (12.3)							
Minshew <i>et al.</i> (1997)	AS	33	20.9 (9.7)	100.9 (13.0)			12.2	12.2		ADI, ADOS, clinical description	12
Minshew <i>et al.</i> (2002)	HFA	90	21.4 (9.7)	98.0 (16.0)	Age, FIQ, gender and race	128 cards				ADI, ADOS, clinical description	10
	HC	33	21.2 (10.0)	100.5 (11.7)							
Child studies											
Kado <i>et al.</i> (2012)	PDD	52	118.5 (29.0) ^a	97.7 (10.1)		Keio version, 48 cards	25	21.2		DSM-IV	10
Kaland <i>et al.</i> (2008)	HC	52	119.7 (33.5) ^a		IQ and age	Computerized 128 cards	0	0	Specialist school	ICD-10, ADI-R, ADOS	12
	AS/HFA	13	16.4 (2.8)	109 (11.5)							
Lam & Yeung (2012)	ASD	12	15.6 (3.1)	109.6 (10.4)	Gender, age, VIP, PIQ				School Child ASD service		10
Li <i>et al.</i> (2014)	HFA	38	9.6 (2.3)	109.8 (18.9)	Age and gender	Computerized	21.1	21.1	Specialist service	DSM-V, ABC, CARS, AQ	8
Pascualvaca <i>et al.</i> (1998)	HC	31	10.2 (1.5)	113.0 (15.1)	PIQ	Manual 128 cards	34.8	34.8	Autism society	DSM-III-R, CARS	15
	ASD	23	8.7 (1.1)	77.6 (14.5)							
Pooragha <i>et al.</i> (2013)	HFA	23	6.7 (1.8)	110.2 (10.2)	Age and education		6.7	15.4	School Hospital		10
	HC	15	9.3 (1.8)	92.7 (7.01)							
Shu <i>et al.</i> (2001)	AS	26	10.1 (2.4)	101.1 (9.1)	Age	Computerized 128 cards			Autism society	DSM-III-R	14
Tsuchiya <i>et al.</i> (2005)	HFA	17	12.5 (4.3)	92.3 (7.5)	Age	Computerized 128 cards	5.9	48	School Paediatric department		10

Williams & Jarrold (2013)	HC	25	12.7 (3.1)	110.2 (16.4) ^b	IQ and age	Computerized and manual	APA, 3Di, SRS	10
	ASD	21	10.5 (2.1)					
Winsler <i>et al.</i> (2007)	HC	21	10.6 (1.3)	107.12 (13.0) ^b	Age	Computerized 64 cards	Community clinics	DSM-V
	ASD	33	11.0 (2.3)					
Yang <i>et al.</i> (2009)	HC	28	10.3 (3.2)	96.7 (24.6)	Age	Community	Hospital clinic	13
	ASD	20	8.1 (3.5)					
	HC	30	8.0 (3.1)	118.2 (12.1)		School	DSM-IV	

ASD, Autism spectrum disorder; *s.d.*, standard deviation; IQ, intelligence quotient; HC, healthy control; WCST, Wisconsin Card Sorting Test; AS, Asperger's syndrome; VIQ, verbal IQ; PIQ, performance IQ; ICD-10, International Statistical Classification of Diseases and Related Health Problems; ADI, Autism Diagnostic Interview; ADOS, Autism Diagnostic Observation Schedule; HFA, high functioning autism; FIQ, full-scale IQ; APA, American Psychiatric Association; GARS, Gilliam Autism Rating Scale; DSM, Diagnostic and Statistical Manual of Mental Disorders; AQ, Autism Spectrum Quotient; CARS, Childhood Autism Rating Scale; PARS, Pervasive Developmental Disorders Autism Society Japan Rating Scale; AQ-J, Autism Spectrum Quotient, Japanese version; PDD, pervasive developmental disorder; ABC, Autism Behaviour Checklist; 3Di, Developmental, Dimensional and Diagnostic Interview; SRS, Social Responsiveness Scale.

^a Measured in months.

^b Performance IQ.

with wider confidence intervals (CIs) than fixed-effects models.

Statistical analysis

Analysis was carried out in STATA 13 (StataCorp, USA) with the following user contributed commands *metan* (Bradburn *et al.* 1998), *metabias*, *metatrim* (Steichen, 1998) and *metareg* (Sharp, 1998). Cohen's *d* was used to estimate the effect sizes and is reported for all studies together with 95% CIs. The effect sizes were interpreted according to Cohen's (1988) definitions of small ($\geq 0.20 \leq 0.50$), medium ($\geq 0.50 \leq 0.80$), large ($\geq 0.80 \leq 1.30$) and very large (≥ 1.30). Positive effect size indicates that the clinical group (ASD or AN) made more perseverative errors than HCs. A *p* value of < 0.05 indicates significant difference between groups.

Risk of bias across studies

Publication bias was assessed by visually evaluating funnel plots of each study's standardized mean differences against its precision and formally by Egger's test (Egger *et al.* 1997) to see if a study's precision was related to effect size (Borenstein *et al.* 2009).

Additional analysis

Between-study heterogeneity was measured by calculating I^2 (Higgins *et al.* 2003) based on Cochran's *Q* test: measure of heterogeneity, $I^2 = 100\% \times (Q - df)/Q$, where *df* is degrees of freedom. I^2 ranges between 0%, indicating no heterogeneity and 100%, indicating high heterogeneity. Child/adolescent studies were analysed separately as well as overall effect size being calculated to explore whether effect was related to participant age. In addition, meta-regression was used to test for differences between ASD and AN participants using diagnosis (AN or ASD) as the moderator.

Results

Study selection

In all, 24 studies in ASD and 22 in AN were included in the meta-analyses consisting of a total of 815 AN participants matched to 956 HCs and 739 ASD participants matched to 760 HCs. The selection process for both AN and ASD studies is shown in Fig. 1.

Study characteristics

All extracted information for AN and ASD studies included in the systematic reviews and meta-analyses is presented in Tables 1 and 2, respectively. Quality

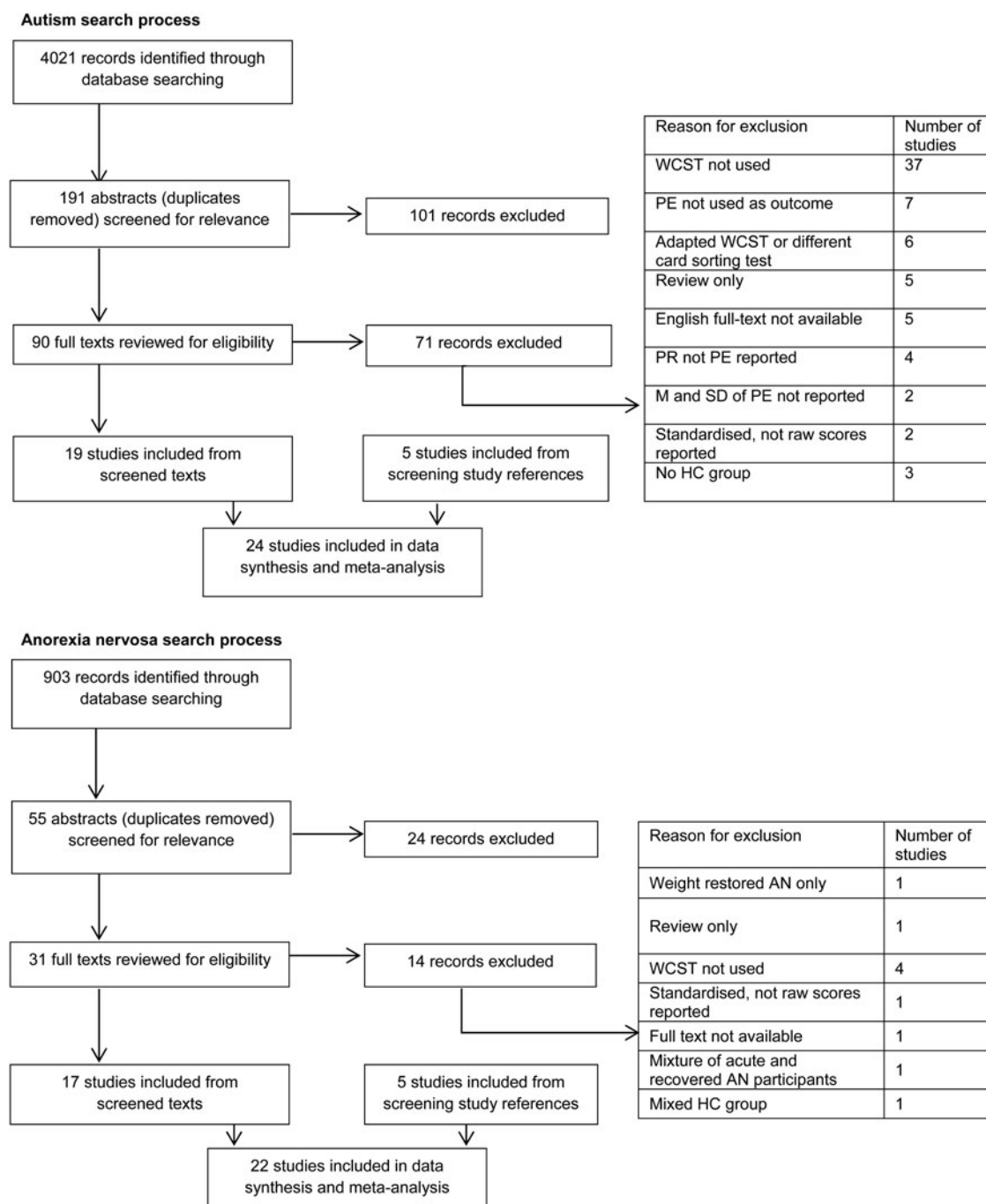


Fig. 1. Systematic review search process. WCST, Wisconsin Card Sorting Test; PE, perseverative error; PR, perseverative response; M, mean; SD, standard deviation; HC, healthy control; AN, anorexia nervosa.

ratings for each study ranged from 16 (highest possible score) to 8 (Li et al. 2014). This study included very little information on the recruitment of clinical participants or HCs but the results were sufficiently detailed for it to be included in the current review. Of the AN studies, the lowest score was 9 (McAnarney et al. 2011). This was presented as a brief report and thus methodological detail was missing. The results of this study were also unclear so the

authors were contacted by K.T. to clarify before data were included in the meta-analysis. The full version of the paper by Koba et al. (2002) was unavailable to the authors at the time of this review; however, as it has been included in previous reviews (Roberts et al. 2007) it was included in the current analysis.

One ASD study (Goldstein et al. 2001) included both child and adult participants. Although the authors did split the ASD participants into ‘old’ and ‘young’ for

analysis, the control group was not split so the pooled results of children and adults, with a mean age of 18 years, were included in the adult meta-analysis. The majority of ASD studies reported IQ which ranged from 77 to 113.1 in the ASD group and 89 to 118 in HCs, indicating no intellectual disability. Nine AN studies also reported IQ, all of which fell within the normal range (97.8–119.5 for AN and 104.9–119.7 for HCs). Of the AN studies, all but two included only female participants, whereas one study included only males (Goddard *et al.* 2014) and one included over 90% of females (Andres-Perpina *et al.* 2011). In the ASD studies three studies included only males, with the other studies ranging from 10 to 48% female participants.

Within both clinical groups, diagnosis varied. For example, within the ASD studies eight papers reported using a diagnosis of ASD, seven used high functioning autism, seven used Asperger's syndrome and one used pervasive developmental disorder. In the AN studies, 17 used a diagnosis of AN while five only included participants with restrictive subtype AN, one of which had a separate binge-purge subtype AN group. Data on mean BMI were also extracted from AN studies and ranged from 14.4 to 19.0 in the AN group. In the ASD studies, diagnosis was given using a variety of clinical measures; eight used both the Autism Diagnostic Interview and the Autism Diagnostic Observation Schedule; 12 used diagnostic criteria taken from the DSM and several self-report measures including the Childhood Autism Rating Scale, the Autism Spectrum Quotient and the Social Responsiveness Scale were also used. In the AN studies, all studies used diagnostic criteria from the DSM, either assessed directly or by using the Structured Clinical Interview for DSM Disorders (SCID; American Psychiatric Association, 2013). One study used the Eating Disorder Examination (Fairburn & Cooper, 1993). Several ASD and AN studies excluded HCs who had a history of psychiatric disorder but few studies reported co-morbidities, although several AN studies assessed for depression, anxiety and/or obsessive-compulsive disorder.

Sources of participant recruitment also differed across studies; in AN studies, 10 studies recruited their AN sample from specialist eating disorder services consisting of a mixture of out-, day- and in-patient treatment. Four studies did not state what type of treatment the participants were receiving; one recruited from an out-patient service; one from an in-patient service and three from psychiatric hospital settings. HCs were recruited from universities, schools or the local community. In nine of the ASD studies, ASD participants were recruited from a variety of specialist, out-patient or in-patient services for people with ASD;

four from autism societies, national registers or research recruitment programmes and one from a specialist school. HCs were recruited from recruitment programmes, schools or the community. Of the ASD studies, 10 were conducted in the USA; four in Japan; three in the UK; two in China and one in the Netherlands, Denmark, Hong Kong, Iran and Taiwan, respectively. Six of the AN studies were conducted in Italy; six in the UK; three in the USA; two in Germany, Japan and Spain and one in Belgium.

Risk of bias

There was good symmetry within all funnel plots indicating no relationship between effect and study size and thus no publication bias. Egger's test indicated no evidence of publication bias (p 's > 0.21). Analysis for correction of publication bias (trim-and-fill method) estimated two missing studies but this did not change the effect size considerably, so uncorrected data are presented here.

Synthesis of results

The forest plot of AN studies included in the meta-analysis is shown in Fig. 2. The random-effects analysis with a total sample size of 1731 (AN = 815, HC = 916) revealed a significant difference between AN and HC groups on the number of perseverative errors on the WCST ($d = 0.43$, 95% CI 0.26–0.61) $z = 4.83$, $p \leq 0.001$). When adult AN studies were analysed separately, there was a significant difference between AN and HC groups with a medium effect size ($d = 0.48$, 95% CI 0.28–0.68, $z = 4.70$, $p \leq 0.001$). When the four child and adolescent studies were analysed separately, there was no significant difference between AN and HC groups ($d = 0.25$, 95% CI –0.05 to 0.55, $z = 1.66$, $p = 0.096$).

The forest plot of ASD studies included in the meta-analysis is displayed in Fig. 3. The random-effects analysis with a total sample size of 1499 (ASD = 739, HC = 760) revealed a significant difference between ASD and HC groups on the number of perseverative errors obtained during the WCST ($d = 0.65$, 95% CI 0.51–0.80, $z = 9.91$, $p \leq 0.001$). For adult studies, there was a medium effect size ($d = 0.68$, 95% CI 0.44–0.91, $z = 5.68$, $p \leq 0.001$). When adolescent studies were analysed separately, the effect size was also medium ($d = 0.51$, 95% CI 0.21–0.82, $z = 3.28$, $p = 0.001$). Child studies produced a medium pooled effect size ($d = 0.70$, 95% CI 0.46–0.92, $z = 5.86$, $p \leq 0.001$).

Additional analysis

There was evidence of moderate heterogeneity in both AN ($I^2 = 63.1\%$) and ASD ($I^2 = 37.0\%$) studies. To

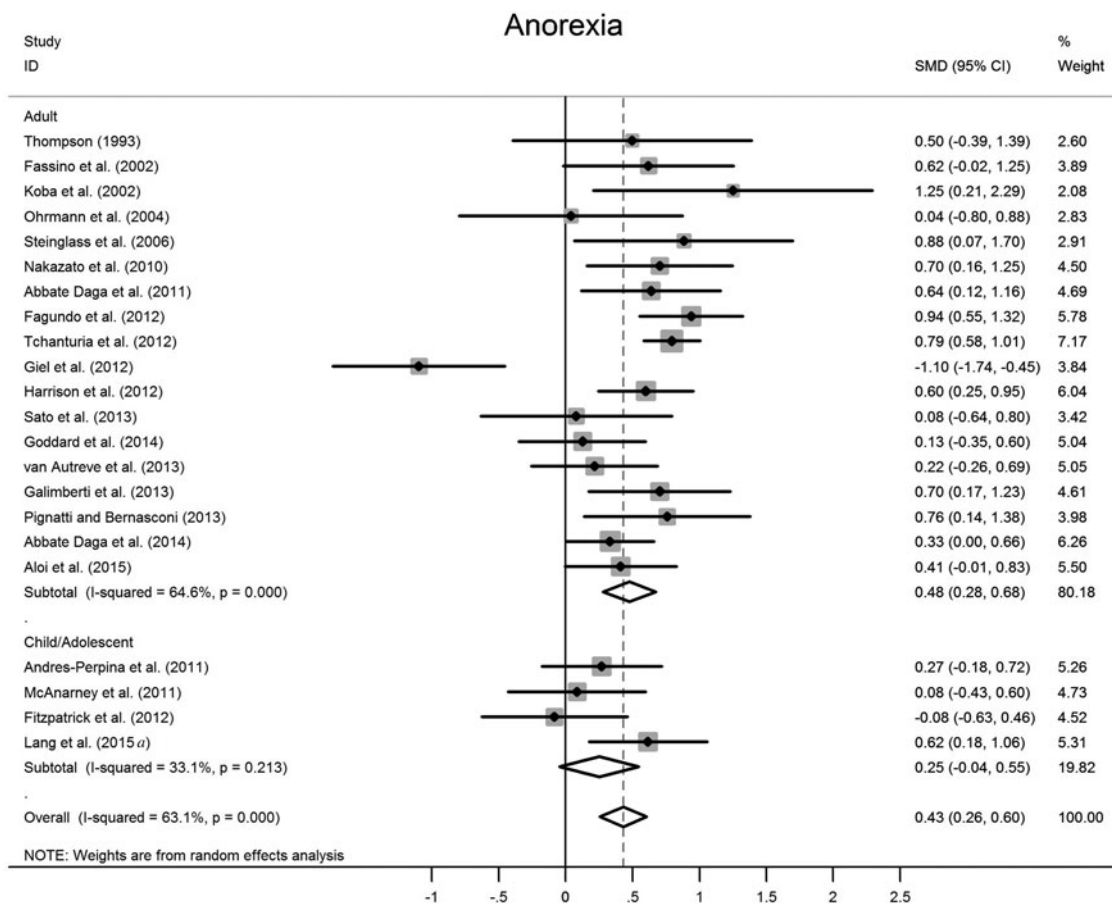


Fig. 2. Forest plot of mean perseverative error score on the Wisconsin Card Sorting Test: standardized mean effect size for differences (SMD) between anorexia nervosa and healthy controls. CI, Confidence interval.

examine the difference between ASD and AN groups, meta-regression was conducted with diagnosis as the moderator. Within adult studies, there was no effect of diagnosis and thus no significant difference between how ASD and AN groups performed on the WCST ($n=28$, mean difference=0.20, 95% CI -0.17 to 0.56 , $t=1.12$, $p=0.274$). There was an almost significant difference between the children and adolescent ASD and AN groups, with the ASD group scoring, on average, worse on the WCST than children and adolescents of the AN groups; however, this difference did not reach significance (mean difference=0.44, 95% CI -0.007 to 0.89 , $n=14$, $t=2.13$, $p=0.053$).

Discussion

The aim of this review was to synthesize the literature on the use of the WCST in both ASD and AN to examine whether there are differences between children and adults both within and between these clinical populations. There were a number of differences between studies including how a diagnosis of either AN or

ASD was given, the service and country in which participants were recruited from, the experimental paradigm used and how HCs were matched to the clinical groups. These differences may have made an impact on the individual outcomes of each study; however, generally the quality of the studies was deemed sufficient for meaningful synthesis and analyses. Studies also differed on the version of the WCST used, for example 128 *v.* 64 cards and computerized *v.* pen-paper versions. This may have had an impact on the results of each study. Children with ASD have been found to perform better on the computerized version of the test, suggesting that the versions are not equivalent and may measure slightly different constructs (Ozonoff, 1995).

The meta-analysis indicated significant differences between participants with AN and HCs, with the AN group making significantly more perseverative errors during the WCST. When children and adults data were analysed separately, the difference between children with AN and HCs was not significant, while in adults the difference remained significant, with a

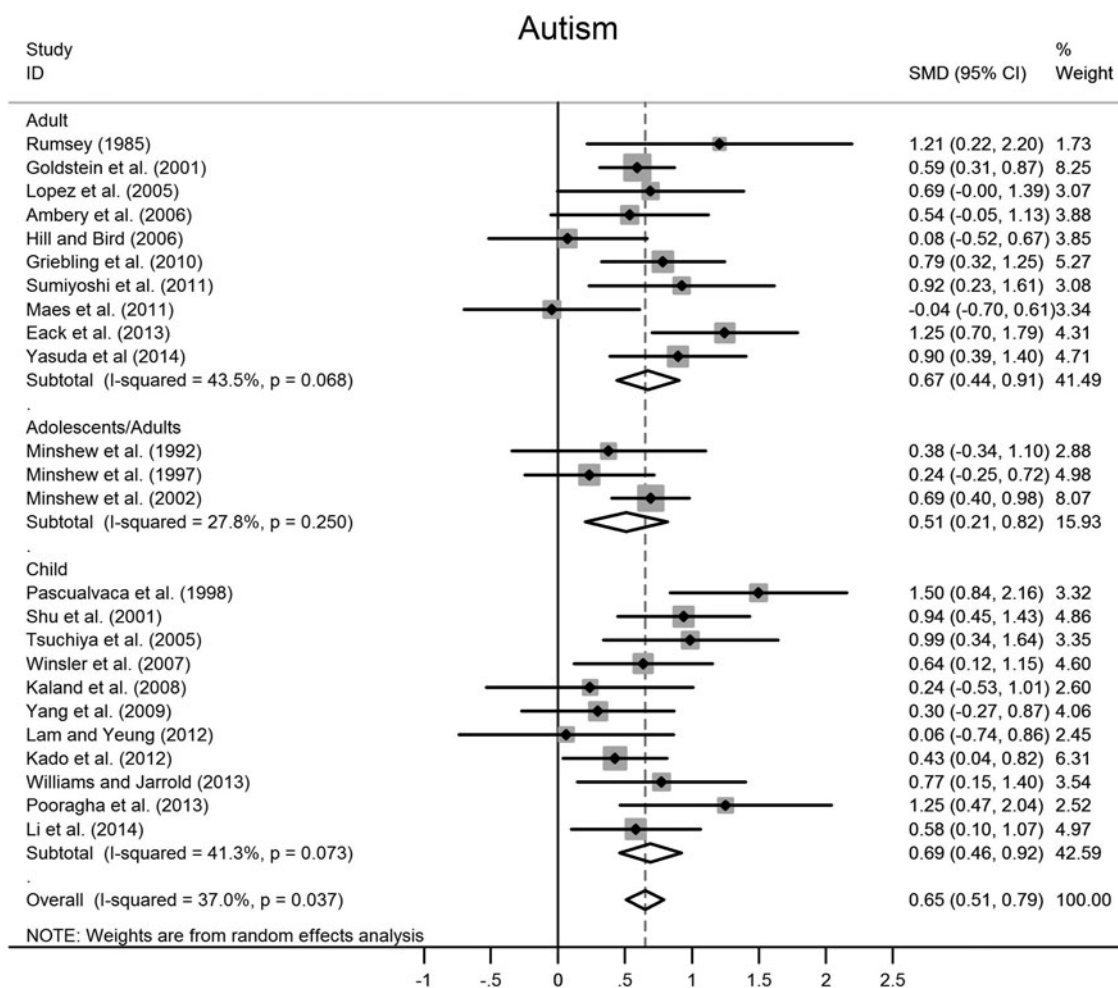


Fig. 3. Forest plot of mean perseverative error score on the Wisconsin Card Sorting Test: standardized mean effect size for differences (SMD) between autism spectrum disorder and healthy controls. CI, Confidence interval.

medium effect size. This indicates that adults with AN may have greater difficulty with set-shifting than young people with the disorder. This finding supports and extends a previous systematic review and meta-analysis (Roberts *et al.* 2007) which showed that adults with AN had significant difficulties with set-shifting relative to HCs. The addition of thirteen studies since Roberts *et al.*'s (2007) meta-analysis has confirmed the original finding of a significant difference between adults with AN and HCs.

The addition of Lang *et al.*'s (2015a) empirical study to the child literature indicates a small non-significant effect of AN on set-shifting, in line with a previous systematic review (Lang *et al.* 2014). This non-significant difference between AN and HC groups may be driven by a lack of statistical power with a limited number of studies conducted with small numbers of participants. The Lang *et al.* (2015a) study was designed to specifically replicate the methods used within adult studies and to address previous methodological shortcomings

in the child literature and therefore adds strength to the current literature, despite the result remaining non-significant. The analysis presented here shows that young people with AN may have difficulties with set-shifting, but further studies are needed to determine whether these difficulties are significant. The effect size in adult studies is larger than that in child/adolescent studies and longitudinal studies are required to properly test whether there is a magnification of the effect over time, whereby poor set-shifting is a risk factor for AN, but is also intensified by the illness, thus acting as a precipitating and perpetuating factor within the disorder. Another possibility is that more severe set-shifting problems during childhood are predictors of the persistence of these problems into adulthood. Alternatively, the WCST may be more reliable and sensitive to problems when used with adults, thus yielding bigger, significant effect sizes in adults.

Meta-analysis of ASD studies indicated a different pattern to the AN studies. Adults with ASD made

significantly more perseverative errors on the WCST in comparison with HCs, indicating significant difficulties with set-shifting with a medium effect size. When child studies were analysed separately, the effect size was also medium, demonstrating that difficulties with set-shifting in ASD appear to be stable across the lifespan. This is a novel finding, as little attention has been paid in the ASD literature to WCST performance across the lifespan; however, these findings support previous work that suggests that deficits on the WCST are stable over time (Huizinga & Van Der Molen, 2007) and studies of executive functioning deficits in children with ASD (Pellicano, 2007; Kimhi *et al.* 2014). The recent meta-analysis by Landry & Al-Taie (2016) found age to be negatively correlated with set-shifting ability. While planned statistical analysis of our review did not specifically test this, CIs for the child and adult studies overlap so we are unable to conclude that there is a significant difference between children and adults with ASD.

Despite difficulties in set-shifting being widely reported within the ASD literature, preserved performance relative to HCs has also been documented in some studies (Ozonoff & Jensen, 1999; Russell & Hill, 2001). Hill (2004) attributes this discrepancy to methodological inconsistencies amongst studies; however, as the meta-analysis performed here only included studies using the WCST, it appears to provide strong evidence that individuals with ASD have problems in set-shifting, at least as assessed using the WCST. This is the first meta-analysis to statistically compare both adult and child ASD studies using the WCST and suggests very little difference between the two groups.

The meta-regression, analysing the impact of diagnosis on set-shifting ability, found no significant difference between ASD and AN, in either the adult or child/adolescent groups, although there was a non-significant trend for children with ASD to perform worse than children with AN. This suggests that there may be differences in the development of set-shifting difficulties across ages between AN and ASD, although larger, stronger-powered longitudinal studies would be needed to confirm this.

It is important to consider the implications of these meta-analyses for both AN and ASD populations. Within AN, interventions like cognitive remediation therapy (CRT) which targets cognitive processes have been developed and empirically tested (Tchanturia *et al.* 2013a, 2014, 2015), with improvements in set-shifting as well as high acceptability and engagement in the treatment being reported. In spite of this success, the use of executive function training in ASD is limited, with a paucity of research in this area (De Vries *et al.* 2015). The few studies that have focused on flexibility

training in ASD have yielded mixed results, with one study reporting improvements in flexibility (Kenworthy *et al.* 2014), one showing no improvement (Fisher & Happe, 2005) and one suggesting a trend towards improvement with intention-to-treat analysis (De Vries *et al.* 2015). These mixed findings may suggest that the type of flexibility training currently offered to individuals with ASD is not suitable for this population. Trials in CRT for ASD are in their infancy but the success of CRT in other disorders along with the observation that children with ASD show development in executive functioning (Pellicano, 2010) makes it a worthwhile focus for future research.

While this review suggests that difficulties with set-shifting are not directly comparable in ASD and AN, its impact on symptoms and wider functioning is still unknown. One of the main cognitive theories of ASD proposes that deficits in executive function underlie the disorder (Russell, 1997) and that these difficulties may also cause problems with social interaction and inflexible behaviour (Pellicano, 2007; Geurts *et al.* 2014). In AN, the cognitive–interpersonal maintenance model of AN (Treasure & Schmidt, 2013) postulates that difficulty with flexibility is a pre-disposing factor for AN, making individuals more susceptible to societal rules and physical appearance. Thus, set-shifting may underlie other symptoms associated with the disorder. The observation that difficulties with set-shifting may underlie other symptoms in both ASD and AN suggests that transdiagnostic interventions which target cognitive style rather than direct symptoms could improve functioning and engagement in other therapies, such as cognitive–behavioural approaches which require a more flexible thinking style (Treasure *et al.* 2015).

This comparison between AN and ASD studies should, however, be interpreted in light of study limitations. The majority of ASD studies only included male participants whereas most AN studies included only females. Thus, there may be important gender differences within each disorder which make an impact on set-shifting ability. For example, in one study adolescent females with ASD outperformed their male counterparts on a test of set-shifting ability (Bolte *et al.* 2011); so if females with ASD were directly compared with females with AN, the results may be different. As starvation is thought to confound set-shifting ability in AN, it is also important to consider variables such as BMI and illness duration on WCST performance, which were not analysed in this review. A study in healthy female participants found set-shifting ability to be impaired after fasting for a 16 h period (Bolton *et al.* 2014), supporting the notion that in females at least, set-shifting is worsened following starvation. Thus, the question of whether poor set-shifting

ability is a trait or state characteristic remains unanswered, despite the evidence from this review suggesting that this difficulty is present in young people with AN. In the future, population-based data, rather than data from clinical samples regarding set-shifting difficulties in those with either subclinical AN or ASD traits, may be useful to avoid bias. The impact of diagnosis was not investigated here and as the diagnostic criteria of ASD and AN have become broader under the revised DSM-V criteria (American Psychiatric Association, 2013), it is possible that greater heterogeneity between studies exists, making studies less comparable.

Acknowledgements

H.W. and K.T. would like to thank the Medical Research Council, Swiss Anorexia Foundation and the Psychiatry Research Trust for their support. D.S. received financial support from the National Institute of Health Research Biomedical Research Centre at South London and Maudsley NHS Foundation Trust and the Institute of Psychiatry, Psychology & Neuroscience, King's College London.

This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Declaration of Interest

None.

References

- Abbate-Daga G, Buzzichelli S, Amianto F, Rocca G, Marzola E, McClintock SM, Fassino S (2011). Cognitive flexibility in verbal and nonverbal domains and decision making in anorexia nervosa patients: a pilot study. *BMC Psychiatry* 11, 162.
- Abbate-Daga G, Buzzichelli S, Marzola E, Amianto F, Fassino S (2014). Clinical investigation of set-shifting subtypes in anorexia nervosa. *Psychiatry Research* 219, 592–597.
- Allely C (2013). Anorexia nervosa – on the autistic spectrum? *Psychologist* 26, 656–658.
- Aloi M, Rania M, Caroleo M, Bruni A, Palmieri A, Cauteruccio M, De Fazio P, Segura-Garcia C (2015). Decision making, central coherence and set-shifting: a comparison between binge eating disorder, anorexia nervosa and healthy controls. *BMC Psychiatry* 15, 6.
- Ambery FZ, Russell AJ, Perry K, Morris R, Murphy DG (2006). Neuropsychological functioning in adults with Asperger syndrome. *Autism* 10, 551–564.
- American Psychiatric Association (2013). *Diagnostic and Statistical Manual of Mental Disorders*, 5th edn. American Psychiatric Association: Washington, DC.
- Andres-Perpina S, Lozano-Serra E, Puig O, Lera-Miguel S, Lazaro L, Castro-Fornieles J (2011). Clinical and biological correlates of adolescent anorexia nervosa with impaired cognitive profile. *European Child and Adolescent Psychiatry* 20, 541–549.
- Atkinson TM, Ryan JP (2008). The use of variants of the trail making test in serial assessment: a construct validity study. *Journal of Psychoeducational Assessment* 26, 42–54.
- Austin MP, Mitchell P, Wilhelm K, Parker G, Hickie I, Brodaty H, Chan J, Eyers K, Milic M, Hadzi-Pavlovic D (1999). Cognitive function in depression: a distinct pattern of frontal impairment in melancholia? *Psychological Medicine* 29, 73–85.
- Baron-Cohen S, Jaffa T, Davies S, Auyeung B, Allison C, Wheelwright S (2013). Do girls with anorexia nervosa have elevated autistic traits? *Molecular Autism* 4, 24.
- Bolte S, Duketis E, Poustka F, Holtmann M (2011). Sex differences in cognitive domains and their clinical correlates in higher-functioning autism spectrum disorders. *Autism* 15, 497–511.
- Bolton HM, Burgess PW, Gilbert SJ, Serpell L (2014). Increased set shifting costs in fasted healthy volunteers. *PLOS ONE* 9, e101946.
- Borenstein M, Hedges LV, Higgins JPT, Rothstein HR (2009). *Introduction to Meta-Analysis*. Wiley: Chichester.
- Bradburn MJ, Deeks JJ, Altman DG (1998). sbe24: metan – an alternative meta-analysis command. *Stata Technical Bulletin*, 44, 4–15. Reprinted in *Stata Technical Bulletin Reprints* 8, 86–100. College Station, TX: Stata Press.
- Cohen J (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd edn. Laurence Erlbaum Associates: London.
- Courty A, Maria AS, Lalanne C, Ringuenet D, Vindreau C, Chevallier C, Pouga L, Pinabel F, Philippe A, Adrien JL, Barry C, Berthoz S (2013). Levels of autistic traits in anorexia nervosa: a comparative psychometric study. *BMC Psychiatry* 13, 222.
- Critical Appraisal Skills Programme (2013). CASP Case Control Checklist. Critical Appraisal Skills Programme. CASP: Oxford (http://media.wix.com/ugd/dded87_63fb65dd4e0548e2bfd0a982295f839e.pdf). Accessed March 2016.
- Danner UN, Sanders N, Smeets PA, Van Meer F, Adan RA, Hoek HW, Van Elburg AA (2012). Neuropsychological weaknesses in anorexia nervosa: set-shifting, central coherence, and decision making in currently ill and recovered women. *International Journal of Eating Disorders* 45, 685–694.
- De Vries M, Prins PJ, Schmand BA, Geurts HM (2015). Working memory and cognitive flexibility-training for children with an autism spectrum disorder: a randomized controlled trial. *Journal of Child Psychology and Psychiatry* 56, 566–576.
- Eack SM, Bahorik AL, McKnight SA, Hogarty SS, Greenwald DP, Newhill CE, Phillips ML, Keshavan MS, Minshew NJ (2013). Commonalities in social and non-social cognitive impairments in adults with autism spectrum disorder and schizophrenia. *Schizophrenia Research* 148, 24–28.
- Egger M, Davey Smith G, Schneider M, Minder C (1997). Bias in meta-analysis detected by a simple, graphical test. *British Medical Journal* 315, 629–634.

- Fagundo AB, De La Torre R, Jimenez-Murcia S, Aguera Z, Granero R, Tarrega S, Botella C, Banos R, Fernandez-Real JM, Rodriguez R, Forcano L, Fruhbeck G, Gomez-Ambrosi J, Tinahones FJ, Fernandez-Garcia JC, Casanueva FF, Fernandez-Aranda F (2012). Executive functions profile in extreme eating/weight conditions: from anorexia nervosa to obesity. *PLOS ONE* 7, e43382.
- Fairburn CG, Cooper Z (1993). The eating disorder examination. In *Binge Eating: Nature, Assessment and Treatment*, 12th edn. (ed. C.G. Fairburn and G.T. Wilson), pp. 317–360. Guilford Press: New York.
- Fassino S, Piero A, Daga GA, Leombruni P, Mortara P, Rovera GG (2002). Attentional biases and frontal functioning in anorexia nervosa. *International Journal of Eating Disorders* 31, 274–283.
- Fisher N, Happe F (2005). A training study of theory of mind and executive function in children with autistic spectrum disorders. *Journal of Autism and Developmental Disorders* 35, 757–771.
- Fitzpatrick KK, Darcy A, Colborn D, Gudorf C, Lock J (2012). Set-shifting among adolescents with anorexia nervosa. *International Journal of Eating Disorders* 45, 909–912.
- Galimberti E, Fadda E, Cavallini MC, Martoni RM, Erzegovesi S, Bellodi L (2013). Executive functioning in anorexia nervosa patients and their unaffected relatives. *Psychiatry Research* 208, 238–244.
- Geurts HM, Corbett B, Solomon M (2009). The paradox of cognitive flexibility in autism. *Trends in Cognitive Science* 13, 74–82.
- Geurts HM, De Vries M, Van Den Beurgh SFWM (2014). Executive functioning theory of autism. In *Handbook of Executive Functioning* (ed. S. Goldstein and J.A. Nagleiri), pp. 121–141. Springer: New York.
- Giel KE, Wittorf A, Wolkenstein L, Klingberg S, Drimmer E, Schoenenberg M, Rapp AM, Fallgatter AJ, Hautzinger M, Zipfel J (2012). Is impaired set-shifting a feature of “pure” anorexia nervosa? Investigating the role of depression in set-shifting ability in anorexia nervosa and unipolar depression. *Psychiatry Research* 200, 538–543.
- Gillberg IC, Billstedt E, Wentz E, Anckarsater H, Rastam M, Gillberg C (2010). Attention, executive functions, and mentalizing in anorexia nervosa eighteen years after onset of eating disorder. *Journal of Clinical Experimental Neuropsychology* 32, 358–365.
- Goddard E, Carral-Fernández L, Denny E, Campbell IC, Treasure J (2014). Cognitive flexibility, central coherence and social emotional processing in males with an eating disorder. *World Journal of Biological Psychiatry* 15, 317–326.
- Goldstein G, Johnson CR, Minshew NJ (2001). Attentional processes in autism. *Journal of Autism and Developmental Disorders* 31, 433–440.
- Greve KW, Ingram F, Bianchini KJ (1998). Latent structure of the Wisconsin Card Sorting Test in a clinical sample. *Archives of Clinical Neuropsychology* 13, 597–609.
- Greve KW, Stickle TR, Love JM, Bianchini KJ, Stanford MS (2005). Latent structure of the Wisconsin Card Sorting Test: a confirmatory factor analytic study. *Archives of Clinical Neuropsychology* 20, 355–364.
- Griebeling J, Minshew NJ, Bodner K, Libove R, Bansal R, Konasale P, Keshavan MS, Hardan A (2010). Dorsolateral prefrontal cortex magnetic resonance imaging measurements and cognitive performance in autism. *Journal of Child Neurology* 25, 856–863.
- Harrison A, Tchanturia K, Naumann U, Treasure J (2012). Social emotional functioning and cognitive styles in eating disorders. *British Journal of Clinical Psychology* 51, 261–279.
- Heaton RK, Chelune GJ, Talley JL, Kay GG, Curtiss G (1993). *Wisconsin Card Sorting Test Manual*. Psychological Assessment Resources, Inc.: Odessa, FL.
- Higgins JP, Thompson SG, Deeks JJ, Altman DG (2003). Measuring inconsistency in meta-analyses. *British Medical Journal* 327, 557–560.
- Hill EL (2004). Executive dysfunction in autism. *Trends in Cognitive Science* 8, 26–32.
- Hill EL, Bird CM (2006). Executive processes in Asperger syndrome: patterns of performance in a multiple case series. *Neuropsychologia* 44, 2822–2835.
- Holliday J, Tchanturia K, Landau S, Collier D, Treasure J (2005). Is impaired set-shifting an endophenotype of anorexia nervosa? *American Journal of Psychiatry* 162, 2269–2275.
- Holmén A, Juuhl-Langseth M, Thormodsen R, Sundet K, Melle I, Rund BR (2012). Executive function tests in early-onset psychosis: which one to choose? *Scandinavian Journal of Psychology* 53, 200–225.
- Huizinga M, Van Der Molen MW (2007). Age-group differences in set-switching and set-maintenance on the Wisconsin Card Sorting Task. *Developmental Neuropsychology* 31, 193–215.
- Huke V, Turk J, Saeidi S, Kent A, Morgan JF (2013). Autism spectrum disorders in eating disorder populations: a systematic review. *European Eating Disorders Review* 21, 345–351.
- Huke V, Turk J, Saeidi S, Kent A, Morgan JF (2014). The clinical implications of high levels of autism spectrum disorder features in anorexia nervosa: a pilot study. *European Eating Disorders Review* 22, 116–121.
- Kado Y, Sanada S, Yanagihara M, Ogino T, Ohno S, Watanabe K, Nakano K, Morooka T, Oka M, Ohtsuka Y (2012). Executive function in children with pervasive developmental disorder and attention-deficit/hyperactivity disorder assessed by the Keio version of the Wisconsin Card Sorting Test. *Brain and Development* 34, 354–359.
- Kaland N, Smith L, Mortensen EL (2008). Brief report: cognitive flexibility and focused attention in children and adolescents with Asperger syndrome or high-functioning autism as measured on the computerized version of the Wisconsin Card Sorting Test. *Journal of Autism and Developmental Disorders* 38, 1161–1165.
- Kenworthy L, Anthony LG, Naiman DQ, Cannon L, Wills MC, Luong-Tran C, Werner MA, Alexander KC, Strang J, Bal E, Sokoloff JL, Wallace GL (2014). Randomized controlled effectiveness trial of executive function intervention for children on the autism spectrum. *Journal of Child Psychology and Psychiatry* 55, 374–383.
- Kenworthy L, Yerys BE, Anthony LG, Wallace GL (2008). Understanding executive control in autism spectrum

- disorders in the lab and in the real world. *Neuropsychology Review* **18**, 320–338.
- Kimhi Y, Shoam-Kugelmas D, Agam Ben-Artzi G, Ben-Moshe I, Bauminger-Zviely N** (2014). Theory of mind and executive function in preschoolers with typical development *versus* intellectually able preschoolers with autism spectrum disorder. *Journal of Autism and Developmental Disorders* **44**, 2341–2354.
- Koba T, Shrie S, Nabeta Y** (2002). Impaired performance of Wisconsin Card Sorting Test in patients with eating disorders: a preliminary study. *Seishin Igaku* **44**, 681–683.
- Lam YG, Yeung SSS** (2012). Cognitive deficits and symbolic play in preschoolers with autism. *Research in Autism Spectrum Disorders* **6**, 560–564.
- Landry O, Al-Taie S** (2016). A meta-analysis of the Wisconsin Card Sorting Task in autism. *Journal of Autism and Developmental Disorders* **46**, 1220–1235.
- Lang K, Lloyd S, Khondoker M, Simic M, Treasure J, Tchanturia K** (2015a). Do children and adolescents with anorexia nervosa display an inefficient cognitive processing style? *PLOS ONE* **10**, e0131724.
- Lang K, Stahl D, Espie J, Treasure J, Tchanturia K** (2014). Set shifting in children and adolescents with anorexia nervosa: an exploratory systematic review and meta-analysis. *International Journal of Eating Disorders* **47**, 394–399.
- Lang K, Treasure J, Tchanturia K** (2015b). Is inefficient cognitive processing in anorexia a familial trait? A neuropsychological pilot study of mothers of offspring with a diagnosis of anorexia nervosa. *World Journal of Biological Psychiatry*. Published online 1 December 2015. doi:10.3109/15622975.2015.1112035.
- Leopold R, Backenstrass M** (2015). Neuropsychological differences between obsessive–compulsive washers and checkers: a systematic review and meta-analysis. *Journal of Anxiety Disorders* **30**, 48–58.
- Leung RC, Zakzanis KK** (2014). Brief report: cognitive flexibility in autism spectrum disorders: a quantitative review. *Journal of Autism and Developmental Disorders* **44**, 2628–2645.
- Lezak MD** (1995). *Neuropsychological Assessment*, 3rd edn. Oxford University Press: New York.
- Li J, Zhu L, Liu J, Li X** (2014). Social and non-social deficits in children with high-functioning autism and their cooperative behaviors. *Research in Autism Spectrum Disorders* **8**, 1657–1671.
- Lindner SE, Fichter MM, Quadflieg N** (2014). Set-shifting and its relation to clinical and personality variables in full recovery of anorexia nervosa. *European Eating Disorders Review* **22**, 252–259.
- Lopez BR, Lincoln AJ, Ozonoff S, Lai Z** (2005). Examining the relationship between executive functions and restricted, repetitive symptoms of autistic disorder. *Journal of Autism and Developmental Disorders* **35**, 445–460.
- Maes JHR, Eling PATM, Wezenberg E, Vissers CTWM, Kan CC** (2011). Attentional set shifting in autism spectrum disorder: differentiating between the role of perseveration, learned irrelevance, and novelty processing. *Journal of Clinical and Experimental Neuropsychology* **33**, 210–217.
- McAnarney ER, Zarcone J, Singh P, Michels J, Welsh S, Litterer T, Wang H, Klein JD** (2011). Restrictive anorexia nervosa and set-shifting in adolescents: a biobehavioral interface. *Journal of Adolescent Health* **49**, 99–101.
- Milner B** (1963). Effects of different brain lesions on card sorting. *Archives of Neurology* **9**, 90–100.
- Minschew NJ, Goldstein G, Siegel DJ** (1997). Neuropsychological functioning in autism: profile of a complex information processing disorder. *Journal of International Neuropsychological Society* **3**, 303–316.
- Minschew NJ, Meyer J, Goldstein G** (2002). Abstract reasoning in autism: a dissociation between concept formation and concept identification. *Neuropsychology* **16**, 327–334.
- Minschew NJ, Muenz LR, Goldstein G, Payton JB** (1992). Neuropsychological functioning in nonmentally-retarded autistic individuals. *Journal of Clinical and Experimental Neuropsychology* **14**, 749–761.
- Moher D, Liberati A, Tetzlaff J, Altman DG, Group P** (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement. *British Medical Journal* **339**, b2535.
- Nakazato M, Hashimoto K, Schmidt U, Tchanturia K, Campbell IC, Collier DA, Iyo M, Treasure J** (2010). Serum glutamine, set-shifting ability and anorexia nervosa. *Annals of General Psychiatry* **9**, 29.
- Nelson HE** (1976). A modified card sorting test sensitive to frontal lobe defects. *Cortex* **12**, 313–314.
- Nielsen S, Anckarsäter H, Gillberg C, Rastam M, Wentz E** (2015). Effects of autism spectrum disorders on outcome in teenage-onset anorexia-nervosa evaluated by the Morgan–Russell Outcome Assessment Schedule: a controlled community-based sample. *Molecular Autism* **6**, 14.
- Odent M** (2010). Autism and anorexia nervosa: two facets of the same disease? *Medical Hypotheses* **75**, 79–81.
- Ohrmann P, Kersting A, Suslow T, Lalee-Mentzel J, Donges US, Fiebich M, Arolt V, Heindel W, Pfeleiderer B** (2004). Proton magnetic resonance spectroscopy in anorexia nervosa: correlations with cognition. *Neuroreport* **15**, 549–553.
- Oldershaw A, Hambrook D, Tchanturia K, Treasure J, Schmidt U** (2010). Emotional theory of mind and emotional awareness in recovered anorexia nervosa patients. *Psychosomatic Medicine* **72**, 73–79.
- Oldershaw A, Treasure J, Hambrook D, Tchanturia K, Schmidt U** (2011). Is anorexia nervosa a version of autism spectrum disorders? *European Eating Disorders Review* **19**, 462–474.
- Ozonoff S** (1995). Reliability and validity of the Wisconsin Card Sorting Test in studies of autism. *Neuropsychology* **9**, 491–500.
- Ozonoff S, Jensen J** (1999). Brief report: specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders* **29**, 171–177.
- Pantelis C, Barber FZ, Barnes TR, Nelson HE, Owen AM, Robbins TW** (1999). Comparison of set-shifting ability in patients with chronic schizophrenia and frontal lobe damage. *Schizophrenia Research* **37**, 251–270.
- Pascualvaca DM, Fantie BD, Papageorgiou M, Mirsky AF** (1998). Attentional capacities in children with autism: is

- there a general deficit in shifting focus? *Journal of Autism and Developmental Disorders* **28**, 467–478.
- Pellicano E** (2007). Links between theory of mind and executive function in young children with autism: clues to developmental primacy. *Developmental Psychology* **43**, 974–990.
- Pellicano E** (2010). The development of core cognitive skills in autism: a 3-year prospective study. *Child Development* **81**, 1400–1416.
- Pellicano L, Hiller R** (2013). Anorexia and autism: a cautionary note. *Psychologist* **26**, 780.
- Pender S, Gilbert SJ, Serpell L** (2014). The neuropsychology of starvation: set-shifting and central coherence in a fasted nonclinical sample. *PLOS ONE* **9**, e110743.
- Pignatti R, Bernasconi V** (2013). Personality, clinical features, and test instructions can affect executive functions in eating disorders. *Eating Behaviour* **14**, 233–236.
- Pooragha F, Kafi SM, Sotodeh SO** (2013). Comparing response inhibition and flexibility for two components of executive functioning in children with autism spectrum disorder and normal children. *Iranian Journal of Pediatrics* **23**, 309–314.
- Rhind C, Bonfioli E, Hibbs R, Goddard E, Macdonald P, Gowers S, Schmidt U, Tchanturia K, Micali N, Treasure J** (2014). An examination of autism spectrum traits in adolescents with anorexia nervosa and their parents. *Molecular Autism* **5**, 56.
- Roberts ME, Tchanturia K, Stahl D, Southgate L, Treasure J** (2007). A systematic review and meta-analysis of set-shifting ability in eating disorders. *Psychological Medicine* **37**, 1075–1084.
- Roberts ME, Tchanturia K, Treasure JL** (2010). Exploring the neurocognitive signature of poor set-shifting in anorexia and bulimia nervosa. *Journal of Psychiatric Research* **44**, 964–970.
- Rumsey JM** (1985). Conceptual problem-solving in highly verbal, nonretarded autistic men. *Journal of Autism and Developmental Disorders* **15**, 23–36.
- Russell J** (1997). *Autism as an Executive Disorder*. Oxford University Press: New York.
- Russell J, Hill EL** (2001). Action-monitoring and intention reporting in children with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines* **42**, 317–328.
- Sanders J, Johnson KA, Garavan H, Gill M, Gallagher L** (2008). A review of neuropsychological and neuroimaging research in autistic spectrum disorders: attention, inhibition and cognitive flexibility. *Research in Autism Spectrum Disorders* **2**, 1–16.
- Sato Y, Saito N, Utsumi A, Aizawa E, Shoji T, Izumiyama M, Mushiake H, Hongo M, Fukudo S** (2013). Neural basis of impaired cognitive flexibility in patients with anorexia nervosa. *PLOS ONE* **8**, e61108.
- Sharp S** (1998). sbe23: meta-analysis regression. *Stata Technical Bulletin*, **42**, 16–22. Reprinted in *Stata Technical Bulletin Reprints* **7**, 148–155. College Station, TX: Stata Press.
- Shu BC, Lung FW, Tien AY, Chen BC** (2001). Executive function deficits in non-retarded autistic children. *Autism* **5**, 165–174.
- Steichen TJ** (1998). sbe19: tests for publication bias in meta-analysis. *Stata Technical Bulletin*, **41**, 9–15. Reprinted in *Stata Technical Bulletin Reprints* **7**, 125–133. College Station, TX: Stata Press.
- Steinglass JE, Walsh BT, Stern Y** (2006). Set shifting deficit in anorexia nervosa. *Journal of International Neuropsychological Society* **12**, 431–435.
- Sumiyoshi C, Kawakubo Y, Suga M, Sumiyoshi T, Kasai K** (2011). Impaired ability to organize information in individuals with autism spectrum disorders and their siblings. *Neuroscience Research* **69**, 252–257.
- Tchanturia K** (editor) (2015). *Cognitive Remediation Therapy (CRT) for Eating and Weight Disorders*. Routledge: Hove, East Sussex.
- Tchanturia K, Davies H, Roberts M, Harrison A, Nakazato M, Schmidt U, Treasure J, Morris R** (2012). Poor cognitive flexibility in eating disorders: examining the evidence using the Wisconsin Card Sorting Task. *PLOS ONE* **7**, e28331.
- Tchanturia K, Lloyd S, Lang K** (2013a). Cognitive remediation therapy for anorexia nervosa: current evidence and future directions. *International Journal of Eating Disorders* **46**, 492–495.
- Tchanturia K, Lounes N, Holtum S** (2014). Cognitive remediation in anorexia nervosa and related conditions: a systematic review. *European Eating Disorders Review* **22**, 454–462.
- Tchanturia K, Morris RG, Anderluh MB, Collier DA, Nikolaou V, Treasure J** (2004). Set shifting in anorexia nervosa: an examination before and after weight gain, in full recovery and relationship to childhood and adult OCPD traits. *Journal of Psychiatric Research* **38**, 545–552.
- Tchanturia K, Smith E, Weineck F, Fidanboyu E, Kern N, Treasure J, Baron Cohen S** (2013b). Exploring autistic traits in anorexia: a clinical study. *Molecular Autism* **4**, 44.
- Thompson SBN** (1993). Implications of neuropsychological test results of women in a new phase of anorexia nervosa. *European Eating Disorders Review* **1**, 152–165.
- Treasure J** (2013). Coherence and other autistic spectrum traits and eating disorders: building from mechanism to treatment. The Birgit Olsson lecture. *Nordic Journal of Psychiatry* **67**, 38–42.
- Treasure J, Cardi V, Lappanen J, Turton R** (2015). New treatment approaches for severe and enduring eating disorders. *Physiology and Behavior* **152**, 456–465.
- Treasure J, Schmidt U** (2013). The cognitive–interpersonal maintenance model of anorexia nervosa revisited: a summary of the evidence for cognitive, socio-emotional and interpersonal predisposing and perpetuating factors. *Journal of Eating Disorders* **1**, 13.
- Tsuchiya E, Oki J, Yahara N, Fujieda K** (2005). Computerized version of the Wisconsin Card Sorting Test in children with high-functioning autistic disorder or attention-deficit/hyperactivity disorder. *Brain and Development* **27**, 233–236.
- Van Aultreuve S, De Baene W, Baeken C, Van Heeringen C, Vervaeke M** (2013). Do restrictive and bingeing/purging subtypes of anorexia nervosa differ on central coherence and set shifting? *European Eating Disorders Review* **21**, 308–314.

- Westwood H, Eisler I, Mandy W, Leppanen J, Treasure J, Tchanturia K** (2016). Using the autism-spectrum quotient to measure autistic traits in anorexia nervosa: a systematic review and meta-analysis. *Journal of Autism and Developmental Disorders* **46**, 964–977.
- Williams D, Jarrold C** (2013). Assessing planning and set-shifting abilities in autism: are experimenter-administered and computerised versions of tasks equivalent? *Autism Research* **6**, 461–467.
- Winsler A, Abar B, Feder MA, Schunn CD, Rubio DA** (2007). Private speech and executive functioning among high-functioning children with autistic spectrum disorders. *Journal of Autism and Developmental Disorders* **37**, 1617–1635.
- Wu M, Brockmeyer T, Hartmann M, Skunde M, Herzog W, Friederich HC** (2014). Set-shifting ability across the spectrum of eating disorders and in overweight and obesity: a systematic review and meta-analysis. *Psychological Medicine* **44**, 3365–3385.
- Yang J, Zhou S, Yao S, Linyan S, McWhinnie C** (2009). The relationship between theory of mind and executive function in a sample of children from mainland China. *Child Psychiatry and Human Development* **40**, 169–182.
- Yasuda Y, Hashimoto R, Ohi K, Yamamori H, Fujimoto M, Umeda-Yano S, Fujino H, Takeda M** (2014). Cognitive inflexibility in Japanese adolescents and adults with autism spectrum disorders. *World Journal of Psychiatry* **4**, 42–48.
- Zucker N, Losh M, Bulik CM, LaBar KS, Piven J, Pelphrey KA** (2007). Anorexia nervosa and autism spectrum disorders: guided investigation of social cognitive phenotypes. *Psychological Bulletin* **133**, 976–1006.