Available online at www.sciencedirect.com
ScienceDirect
Brain and Cognition 65 (2007) 77–86
Brain and Cognition
www.elsevier.com/locate/b&c

Deconstructing executive deficits among persons with autism: Implications for cognitive neuroscience

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Accepted 3 April 2006

Abstract

Individuals with autism demonstrate impairments on measures of executive function (EF) relative to typically developing comparison participants. EF is comprised of several processes including inhibition, working memory and set shifting that develop throughout the lifespan. Impairments in EF may appear early in development and persist, or may represent a more transient delay which resolves with time. Given the unevenness of the cognitive profile of persons with autism, understanding the development of EF poses methodological challenges. These issues include those related to matching measures and the choice of comparison participants to which the performance of persons with autism will be compared. In the current review, we attempt to break down the processes of inhibition, working memory and set shifting among persons with autism. We propose to do this within a developmental perspective that highlights how matching measures and comparison participants can affect the interpretation of research findings.

Keywords: Autism; Executive function; Cognitive development; Methodology

1. Introduction

Damasio and Maurer's (1978) observation that persons with autism display some behaviors that are similar to those of persons with frontal lobe damage was a turning point in the study of autism. The commonalities between the two groups—including difficulties in switching between tasks (Damasio & Maurer, 1978), planning immediate and future activities, and acquiring and modulating social rules (Eslinger & Damasio, 1985)—initially suggested that the behaviors of persons with autism, just as those of persons with frontal lobe damage, might be linked to specific neurological damage. This conceptual link between behavior and brain led to the development of theories of executive dysfunction in autism, as executive, or higher-order, functions are thought to be controlled in the frontal lobes. Following the first identification of executive function (EF) difficulties among persons with autism, subsequent research focused on fine tuning the nature of the executive impairments by isolating intact and impaired processes. The evidence of impairment appears to be consistent across studies and convincing for some aspects of executive function, but less so for others. In this article, we review the current state of knowledge of EF processes among persons with autism. Specifically, we attempt, through a review of the literature, to examine the development of the EF processes of inhibition, working memory and set shifting in this population. In so doing, we emphasize the ways that methodological concerns regarding the researcher's choice of matching measure, comparison groups, and develop-

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0278-2626/$ - see front matter
doi:10.1016/j.bandc.2006.04.007

mental levels of the participants can impact the interpretation of findings across studies of EF.

2. Considerations in the study of EF among persons with autism

The study of EF abilities among persons with autism requires an integration of the consideration of both typical developmental patterns and of the uneven development that is characteristic of persons with autism. EF is a broad term that encompasses several components of cognition such as inhibition, set shifting, working memory, and planning, and develops throughout childhood and adolescence among typically developing persons (Zelazo & Muller, 2002). The charting of the development of EF processes among persons with autism is compounded by methodological concerns, including the developmental level of participants, the selection of relevant matching measures and the choice of comparison participants (for a review of these methodological concerns, see Burack, Iarocci, Flanagan, & Bowler, 2004). The sheer number of permutations between the EF processes that are studied, the developmental levels of participants, the ways that levels of EF are attained, and the comparison groups utilized, complicates the development of a definitive story of EF function among persons with autism. The performance of individuals with autism may be impaired for some components of EF but not others, on some tasks but not others, at some points in development and not others, and in relation to some matching measures or some comparison groups but not others.

Among typically developing persons, the maturation of EF processes is reflected in the ability to be more future oriented, less stimulus bound, and less concrete (Inhelder & Piaget, 1964; Pennington & Ozonoff, 1996). The development of EF is characterized by an inverted U-shaped curve (Zelazo, Craik, & Booth, 2004) with childhood and adolescence representing a period of steady development that peaks in young adulthood among typically developing persons. These developmental patterns suggest that EF processes and deficits are dynamic and need to be considered within a framework of developmental theory and methodology.

2.1. Matching issues

2.1.1. Choice of matching measures

Individuals with autism demonstrate a characteristic cognitive profile with significant strengths and weaknesses that generally includes a relative strength on visual–spatial nonverbal measures and a concurrent weakness in verbal ability (Burack, Iarocci, Bowler, & Mottron, 2002; Happé, 1994; Joseph, Tager-Flusberg, & Lord, 2002) This uneven profile muddies comparisons of performance on EF, or any other types of tasks, between groups of persons with autism and typically developing children for whom verbal and nonverbal abilities are inherently similar (Burack et al., 2004). For example, most measures of verbal abilities underestimate the performance of persons with autism in relation to performance abilities and, therefore, lead to matched comparisons with younger participants and an inevitable overestimation of the abilities of the persons with autism on the experimental task. Conversely, the use of certain visual–spatial tasks with which the scores of persons with autism are overinflated would lead to comparisons with older, higher functioning, persons and therefore an underestimation of abilities. The option of matching on the basis of IQ is advocated by some for averaging strengths and weaknesses, but does not allow for the consideration of the specific cognitive abilities involved in the performance of the experimental task. At a general level, if a task largely involves verbal abilities, then matching on the basis of overall IQ would lead to an underestimation of performance, whereas the converse is true if the task is primarily visual–spatial in nature. Thus, both the nature of experimental tasks and the matching measures utilized in comparing the performance groups need to be considered together such that the choice of matching measure reflects some important characteristic of the experimental task for which any a prior differences are controlled (Burack et al., 2004).

The significance of these matching issues is a highlighted in a study of the performance of children with autism on the Dimension Change Card Sort (DCCS), a measure of cognitive flexibility (Burack et al., 2002) on which developmental changes were observed between 3 and 6 years among typically developing children (e.g., Frye, Zelazo, & Palfai, 1995). The children with autism and the typically developing children showed similar levels of performance when they were matched individually on receptive language ability (Peabody Picture Vocabulary Test, PPVT; Dunn & Dunn, 1997), but the children with autism showed impaired performance when the matching was on the basis of a nonverbal IQ measure (the Brief-IQ of the Leiter-R; Roid & Miller, 1997). Thus, depending on the matching strategy used, individuals with autism, either do or do not, demonstrate impairments in their ability to successfully complete the DCCS. Given the verbal nature of the DCCS, verbal ability, seems a more appropriate matching strategy than matching on the basis of nonverbal ability, as it would allow for matching on a characteristic of the experimental task. One must, however, consider that matching on the basis of verbal ability is likely to overestimate the performance of persons with autism. These findings provide one example of the way in which matching strategies can affect the outcome and interpretation of the studies of EF in autism.

2.1.2. Choice of comparison groups

Comparison groups provide information regarding the standing of one group in relation to another (Burack et al., 2002). The choice of comparison groups impacts the types of conclusions that can be drawn from research. Findings in relation to typically developing children inform us about differences from the norm (e.g., the presence or absence of a relative strength or weakness), while comparisons to atypical groups inform us about the uniqueness of the patterns of abilities and deficits of the target group. Atypical groups with very different phenotypes than those of persons with autism are similarly considered to have executive impairments (e.g., Ozonoff & Jensen, 1999), but because EF is comprised of a number of processes, these processes may be differentially impaired across groups. Accordingly, the charting of EF processes that are intact or impaired at different points in development among persons with autism is useful for fine tuning the notion of an EF deficit in this group and would thus allow for the delineation of characteristic profiles of strengths and weaknesses.

3. The example of perseveration on the WCST among persons with autism

The empirical search for EF deficits in autism was initiated by Rumsey (1985) who found that persons with autism, similar to persons with frontal lesions, display an increased number of perseverative responses on the Wisconsin Card Sorting Test (WCST) compared to persons matched for IQ, gender, education and age. Perseverative responses on the WCST are thought to reflect impairments in cognitive flexibility, which can be seen among persons with autism in everyday resistance to change, and difficulty with transitions between activities. Individuals with autism consistently display increased numbers of perseverative responses on the WCST relative to typically developing comparison participants matched on IQ and age (e.g., Ozonoff & McEvoy, 1994; Ozonoff, Pennington, & Rogers, 1991; Prior & Hoffman, 1990; Rumsey, 1985; Rumsey & Hamburger, 1988; Szatmari, Tuff, Finlayson, & Bartolucci, 1990), as well as to persons with Attention Deficit Hyperactivity Disorder (ADHD) and Tourette syndrome (TS; Ozonoff & Jensen, 1999). This finding provides a clear example of EF dysfunction among persons with autism, although it is certainly not evidence of a generalized EF deficit as cognitive flexibility represents only one of many components of EF, and the WCST is only one task of cognitive flexibility.

The impaired performance on the WCST is generally attributed to difficulties with cognitive flexibility; but perseveration may represent deficits beyond those associated with cognitive flexibility as performance on this task is thought to reflect abilities in other areas of EF (Bond & Butchel, 1984; Ozonoff, 1995). For example, success on the WCST requires that an individual be able to stop a current behavior, remember and keep active the rules and objectives of the task, and change strategies in order to sort by new, incompatible rules. These components correspond to the executive functions of inhibition, working memory, and set shifting, a three factor structure of EF that is supported by factor analytic studies (Miyake et al., 2000; Zelazo & Muller, 2002). Within each of these areas, differences of operationalization and task design affect the interpretation of research findings and the understanding of EF processes among persons with autism.

3.1. Inhibition among persons with autism

Response inhibition is defined as the interference or prevention of a behavioral response in the presence of the stimulus for that response (Barkley, 1997; Brian, Tipper, Weaver, & Bryson, 2003). For example, individuals with ADHD, who are known to have inhibition difficulties, might blurt out the answer to a question in class, despite knowing that they should first raise their hand and wait to be called on by the teacher. Changes in inhibitory control are noted in the preschool years of typically developing children (Jones, Rothbart, & Posner, 2003) through to adulthood (Schachar & Logan, 1990). With age, the number of errors committed on measures of inhibition, decreases (Tamm, Menon, & Reiss, 2002). Simultaneously, the brain areas activated by these processes reflect increased specialization (Tamm et al., 2002), suggesting that processing becomes more efficient with age. Based on the premise that more accurate performance reflects increased specialization, we suggest that developmental level is a relevant factor to consider in the study of response inhibition among persons with autism.

Perseverative responses on the WCST can be due, in part, to difficulties at the level of response inhibition, as is the case among persons with ADHD (Ozonoff & Jensen, 1999). In order to determine whether inhibitory difficulties affect the performance on the WCST of persons with autism, more direct measures of response inhibition need to be utilized, particularly those measures that reflect the same underlying processes required for the successful completion of the task. On the WCST, individuals with inhibition difficulties are less able to terminate a response strategy in order to initiate another, and require additional trials to achieve a successful switch between card dimensions. Competition between two responses is the basis for the construction of direct measures of response inhibition such as the Stroop (Stroop, 1935), Go/No-Go (Ozonoff & McEvoy, 1994), Stop-Signal (Logan, Cowan, & Davis, 1984), Negative Priming tasks (Ozonoff & Strayer, 1997), Windows Task (Hughes & Russell, 1993) and Detour Reaching Task (Bíro & Russell, 2001). Theoretically, these less demanding tasks allow for the examination of inhibitory function in younger children without confounding the effects of cognitive flexibility and working memory.

3.1.1. The Stroop task

Eskes, Bryson, and McCormick (1990) used the Stroop Task to study the inhibitory processes of children with autism, with chronological ages from 8 and 19 years, in relation to typically developing children matched on the basis of reading ability. In the Stroop task, participants are presented with color words—such as the words red, yellow, and blue—which are printed in a color of ink that is incompatible with the color word. For example, the word red might be printed in blue ink. The participants are told to name the color of the ink in which the word is printed, while ignoring the printed word. Although participants are told to ignore the written word, differences in reading ability will affect task performance; the interference between the two salient responses is minimized if the participant is unable to read. Matching on the basis of reading ability ensures that participants, on average, experience the same interference between the two salient responses and, thus, minimizes the probability that group differences be falsely interpreted as an inhibitory impairment. Eskes et al. (1990) found no group differences on this task.

Russell, Jarrold, and Hood (1999) used the day/night version of the Stroop task (Gerstadt, Hong, & Diamond, 1994), designed for younger children and with no reading prerequisite, in a comparison of children with autism and typically developing children matched on verbal mental age and a group of children with moderate intellectual impairments matched on both verbal and chronological ages. The chronological ages varied between 72 and 204 years of age, whereas the verbal mental ages, measured with the British Peabody Picture Vocabulary Test, ranged between 63 and 104 months. The finding of no group differences between the children with autism and typically developing children must be interpreted with some caution. As matching on the basis of a cognitive weakness, such as receptive language, generally leads to comparisons with younger, lower functioning, comparison participants and a subsequent underestimation of performance, then the failure to find deficits in response inhibition may be due to the choice of matching measure rather than to intact abilities.

Ozonoff and Jensen (1999) used the Stroop task to compare the performance of children with autism between the ages of 6 and 18 years to groups of typically developing children, children with ADHD, and those with TS, matched on chronological age. In this study, IQ was considered a covariate. Although differences were noted between the verbal, performance, and full-scale IQs of the children with autism and typically developing children, the performance of children with autism was no different than the performance of the typically developing children and children with TS.

In summary, the Stroop task is used to assess the response inhibition of children with autism in three studies (Eskes et al., 1990; Ozonoff & Jensen, 1999; Russell et al., 1999). The performance of the children with autism of varying mental and chronological ages was assessed with this task. Among children with both high and low mental ages, the performance of the persons with autism on the Stroop task was generally comparable to that of typically developing children. These findings were noted when the developmental levels of the children were measured with tests of either full-scale IQ or language abilities. Between the ages of 6 and 18 years, children with autism seem to be better at inhibiting a prepotent response than children with ADHD, and as capable as matched typically developing comparison participants, and children with TS. As inhibition is thought to develop between the ages of 3 and 20 years, the inhibitory capacity of children with autism appears to follow a normal developmental trajectory, at least after the developmental level of 6 years. This evidence suggests that response inhibition as it relates to the WCST is spared among school age children and adolescents with autism.

3.1.2. Go-No/Go task

In an attempt to examine the nature of perseverative errors on the WCST, Ozonoff, Strayer, McMahon, and Filloux (1994) examined the inhibitory control of high functioning children with autism between the ages and developmental levels of 8 and 16 years compared to typically developing children and children with TS. The groups were matched on the basis of age, gender, and verbal, performance and full-scale IQ. The authors used the Go/No-Go task to tease apart inhibitory processes from those reflecting cognitive flexibility. The Go/No-Go task includes three separate conditions of inhibition of neutral responses, inhibition of prepotent responses, and cognitive flexibility. In the first condition, participants are required to press a button in response to a specific stimulus such as a blue square. In the second condition, participants are given the same instruction but are, instead, told to withhold their responses when they see a blue cross. In the third condition, participants are required to press the key when they see a blue cross but to withhold a response when a square appears. Ozonoff et al. (1994) found that the children with autism were as accurate as age and IQ matched comparison participants to inhibit responses in the ‘neutral response’ condition, demonstrated a slight delay in the inhibition of the prepotent responses condition, and were significantly impaired at shifting response sets. The delay in the inhibition of prepotent responses appears to be inconsistent with the evidence of intact inhibition that was found in studies where the Stroop task was used, but Ozonoff and McEvoy (1994) note that success on the inhibition of the prepotent response condition requires participants to switch mental sets to the new target category. Thus, deficits on this condition among persons with autism seems to arise from the initial need for set shifting rather than any specific difficulties with inhibition per se (Ozonoff et al., 1994).

3.1.3. Stop-Signal and negative priming tasks

Ozonoff and Strayer (1997) attempted to delineate the processes of inhibition and set shifting, while studying the complementary components of inhibitory control at both the motor and cognitive levels. The performance of individuals with autism on both the Stop-Signal (Logan et al., 1984) and the Negative Priming task (Tipper, 1985) was compared to IQ and age matched typically developing participants. Both the typically developing children and the children with autism were on average 13-years-old and displayed average IQs. The Stop-Signal task requires that children sort words into categories (e.g., animals and non-animals). On some trials, a tone is sounded and sorting must be inhibited. On the Negative Priming task, participants are presented with a series of letters such as

TNTNNT and asked whether the second and fourth letters are the same. On some trials, the target letters are the same as the distractors from the previous trial. Increased reaction time to this interference from preceding trials is considered an index of intact inhibition (Neill, Lissner, & Beck, 1990). The performance of adolescents with autism was within normal limits on both of these measures. These findings are evidence that adolescents with autism display both the motor control to inhibit a response and the ability to consciously control the act of withholding that response.

3.1.4. Windows and detour reaching tasks

Russell and colleagues developed the Windows task (Hughes & Russell, 1993; Russell, Mauthner, Sharpe, & Tidswell, 1991) and the Detour Reaching task, (DRT; Bíro & Russell, 2001) to measure the inhibition abilities of children with autism. Their participants with autism were impaired on both of these measures compared to typically developing children and children with moderate intellectual impairments who were matched on receptive language level. On the Windows tasks (Hughes & Russell, 1993), children are required to either deceive an opponent by pointing to one of two boxes (the empty one) in order to obtain a treat, whereas the DRT requires children to learn which of two routes, the knob route or the switch route, releases a marble. The children with autism committed more perseverative errors on both tasks as compared to children with moderate intellectual impairments. These groups were matched on both verbal and nonverbal mental ages. The perseverative responses on the Windows task were interpreted as reflecting a difficulty with disengaging mentally from an object, and the difficulty exhibited by persons with autism on the DRT was attributed to the arbitrariness of the knob route procedure. Both the Windows and DRT tasks include basic rule structures that need to be manipulated for successful performance. Although an inhibitory component is inherent to the Windows and DRT tasks, concurrent demands are placed on the understanding, and planful use of rules, as well as the ability to switch mentally between them. Since the inhibitory abilities of persons with autism are consistently found to be intact, the difficulties with other processes such as cognitive flexibility and/or mental disengagement likely contribute to the impaired performance of persons with autism on the Windows and DRT tasks.

Across the studies reviewed above, direct and indirect measures of response inhibition, multiple matching groups, developmental levels, and comparison participants, were utilized to assess the relative performance of children with autism with regard to inhibition of prepotent responses. In all the studies in which the inhibitory processes of persons with autism were tested directly, such as the Stroop and the first condition of the Go/No-Go task, the performance of children and adolescents with autism was intact. The performance of the children with autism was equivalent to that of the typically developing children, as well as of children from other atypical groups with no inhibitory impairments, such as children with TS and children with moderate intellectual abilities. On indirect measures of inhibition, such as the second and third conditions of the Go/No-Go tasks, the Windows task (Hughes & Russell, 1993; Russell et al., 1991) and DRT (Bíro & Russell, 2001), individuals with autism performed worse than verbal age matched typically developing children. These two tasks appear to reflect more than simple inhibitory processes that tap into cognitive flexibility and mental disengagement, and thus complicate the interpretation of findings. This evidence suggests that the perseverative response style of adults with autism on the WCST does not appear to be related to underlying difficulties in response inhibition.

3.2. Working memory and autism

Developmental gains in working memory ability are noted among typically developing children between the ages of 4 and 8 years, at which point adult performance is reached on some measures (e.g., Lucianna & Nelson, 1998). Working memory includes components of cognition that are essential to representing and understanding the immediate environment by keeping active incoming information for further processing. It is useful for problem solving and developing, relating and acting on current goals (Baddeley, 1992, 1998; Jarrold & Baddeley, 2001). Working memory can also be examined in terms of its capacity, or the number of elements that can be held online simultaneously. The disparities between the two ways of operationally defining working memory inevitably lead to differences in the choice and nature of the experimental tasks that are used to study it.

Working memory is considered essential to performance on the WCST because the task requires concurrent storage and utilization of information from completed sorts while processing information on each new card that is presented (Berman et al., 1995; Dehaene & Changeux, 1991; Kimberg & Farah, 1993). Difficulties in updating the content of working memory would impair remembering to switch to a new sorting dimension, and thus contribute to the presence of perseveration on this task. In contrast, working memory span, or the amount of information that can be kept active at once, appears unrelated to performance on the WCST. The evidence for working memory impairments among persons with autism includes evidence of both impaired (Bennetto, Pennington, & Rogers, 1996; Frith, 1970; Minshew & Goldstein, 2001) and similar (Griffith, Pennington, Wehner, & Rogers, 1999; Ozonoff & Strayer, 1997; Russell, Jarrold, & Henry, 1996) performance relative to typically developing children and children with other disabilities, such as mental retardation.

Differences in the types of comparison participants led to differences in the findings relevant to working memory in autism. For example, evidence of intact working memory functioning is typically found in studies in which persons with autism are compared to those with intellectual disabilities, whereas impairments in working memory performance were generally noted in studies in which comparison were made to typically developing persons. In one case, Minshew and Goldstein (2001) tested and noted impairments in the working memory of adolescents and adults with autism between 12 and 40 years and with average IQs in relation to typically developing persons matched on age and IQ. In contrast, Griffith et al. (1999) and Russell et al. (1996) found no working memory impairments among children with autism compared to children with moderate intellectual disabilities. The two groups in the Griffith et al. (1999) study included children with autism and children with intellectual impairments with mean chronological ages of 4 years 3 months, verbal MA's of 22 months, and nonverbal MAs of 34 months. Russell's (1996) groups included children with autism and children with moderate intellectual disabilities with average chronological ages of 12 years, and average verbal mental ages of 6 years, 3 months. The discrepancy in findings in relation to the comparison groups and developmental levels of the groups suggests that working memory deficits are likely not present throughout development (Hoeksma, Kemner, Verbaten, & van Engeland, 2004), and may apply only to tasks that measure working memory span.

Methodological inconsistencies regarding the choice of tasks used to measure working memory may also, in part, explain the mixed findings regarding working memory ability among persons with autism. In the studies in which significant group differences were found between children with autism and typically developing children, working memory was assessed as a function of memory span, either auditory or visual (Frith, 1970). In contrast, in those studies in which no group differences were noted, the working memory measures utilized did not include systematic increases in working memory load. Instead, these interference tasks require the performance of a non-meaningful activity (e.g., counting) while trying to keep online pertinent information for later recall. For example, Bennetto et al. (1996) found that, in comparison to typically developing children matched on verbal IQ, children with autism were impaired on working memory tasks that measured temporal order and sentence and counting span. In contrast, Russell et al. (1996) and Ozonoff and Strayer (2001) found no group differences on their working memory measures of interference in relation to typically developing children matched on receptive language (Russell et al., 1996) and verbal, performance and full-scale IQ (Ozonoff & Strayer, 2001). The differences between the underlying structure of span tasks and interference tasks suggest that select components of working memory are impaired in autism. Specifically, interference tasks requiring an inhibition component appear intact among children with autism while auditory and visuo-spatial span abilities appear impaired.

Further work in this area is needed in order to clarify the construct of working memory as well as the presence or absence of deficits or delays among persons with autism. Although the performance of individuals with autism appears impaired in terms of span abilities, those components of working memory that more accurately reflect the working memory demands of the WCST appear spared in autism. The review of the literature suggests that, similar to inhibitory processes, working memory processes do not contribute to the increased perseveration on the WCST by persons with autism.

3.3. Set shifting/cognitive flexibility and autism

The finding of increased perseveration on the WCST by persons with autism (e.g., Rumsey, 1985) is generally attributed to difficulties in the area of set shifting. Set shifting refers to the ability to shift to a different thought or action according to changes in a situation, and can be seen in the difficulties that individuals with autism experience with respect to transitions. Children with autism often experience emotional distress if familiar routines are changed, such as changes in who is picking them up from school, or changes to their classroom schedule.

The development of set shifting among typically developing persons appears to follow the inverted U-shaped curve that characterizes EF development, and important developments in representational flexibility are noted among preschool children (Jacques, Zelazo, Kirkham, & Semcesen, 1999) between the ages of 3 and 6 years (Frye et al., 1995; Zelazo, Muller, Frye, & Marcovitch, 2003). The Dimensional Change Card Sorting task (DCCS; Frye et al., 1995), Intradimensional/Extradimensional shift task (ID/ED shift) and the A-not-B tasks (with and without invisible displacement) are used to assess cognitive flexibility in children with autism. These three tasks require the ability to switch flexibly between rules or response sets, but unlike the DCCS and ID/ED shift, the A-not-B tasks do not require children to switch mental sets to new target categories. In the study of set shifting among persons with autism, tasks that tap these processes at different developmental levels have been utilized. The A-not-B tasks are suitable for infants and toddlers, and on the DCCS developmental changes are noted between the ages of 3 and 6 years. More difficult tasks such as the ID/ED shift and WCST are appropriate for older children, adolescents and adults. Although the complexity level of these tasks is not identical, the examination of the ability of persons with autism to complete these tasks at different points in development provides an idea of whether these processes may be impaired in children like they are among adults with autism.

Griffith et al. (1999) tested young children with autism (mean chronological age of 51 months, verbal age of 22 months, and nonverbal mental age of 37 months) on several measures of EF, including the A-not-B and the A-not-B with invisible displacement tasks, and compared their performance to matched children with developmental delays. As the A-not-B tasks are more difficult for monkeys with dorsolateral frontal ablations than for monkeys with intact brains, these tasks appear to tap executive processes.

On both A-not-B tasks, a toy is placed in one of two identical wells at the child's midline. After the successful retrieval of the toy by the child from the same well on two consecutive occasions, the location of the toy is switched to the other well. In the standard A-not-B version of the task, the child sees the toy being shifted, while on the invisible displacement version, the well containing the object is moved out of the child's sight. No significant differences were noted for either of these tasks, but the performance of children with autism tended to be poorer than that of the comparison participants on the invisible with displacement version. This significant trend was in contrast to all the other experimental measures used in the Griffith et al. (1999) study in which the performance of persons with developmental delays was similar to that of the children with autism. The results of this study suggest that young children with autism are able to shift sets as well as children with developmental delays, however, they cannot provide evidence regarding whether the performance of both groups differed from that of typically developing children.

Frye et al. (1995) designed the Dimensional Change Card Sort, as a developmentally appropriate version of the WCST for use with preschool children. This task requires children to sort cards according to two incompatible dimensions, color and shape, rather than the four dimensions used for sorting on the WCST. On each trial, the children are told the relevant sorting rule, thus eliminating working memory and planning abilities as potential confounds. In the standard DCCS, the children are first asked to sort cards according to one dimension (e.g., shape). After five successful trials, the rule is changed, and the participants are asked to sort by the second dimension (e.g., color). In the more difficult border version, children need to switch flexibly between two incompatible dimensions within the same set. In this more complex phase, half the test cards have a border around them, and children are asked to sort according to one rule if the card has a border and according to another rule if the card has no border. Successful performance on this task requires the conscious control of thought and action and the ability to switch flexibly between dimensions, and is mediated by verbal abilities as children are asked to follow verbal rules. Among typically developing children, changes in performance are noted between the ages of 3 and 6 years (Zelazo, Frye, & Rapus, 1996). Three and 4-year-olds are able to sort by the first dimension, 5-year-olds are able to switch to an incompatible set of rules, and 6-years-olds are able to switch flexibly between rules (Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Zelazo et al., 1996).

The performance of both low (verbal IQ less than 40; mean verbal mental age of 4.07 years, and mean chronological age of 17.47 years) and high functioning (verbal IQ greater than 40, mean verbal mental age of 6.15 years, and mean chronological age of 10.3 years) children with autism was assessed with DCCS and other EF tasks including two measures of Theory of Mind (Tom), the explicit false belief task, and the unexpected contents task (Zelazo, Jacques, Burack, & Frye, 2002). The performance of a group of higher functioning children with autism on the DCCS was highly related to their performance on the Theory of Mind tasks ($r = .82$), while this relation was not significant for the lower functioning group. Since young children with autism are generally impaired on measures of ToM, their performance would likely also be impaired on the DCCS, but because no comparison group was utilized by Zelazo et al. (2002), the conclusion of impairments in set shifting is difficult to determine. In a commentary published as part of the same special issue, Colvert (2002) replicated the Zelazo et al. (2002) findings of a high correlation between children's performance on the DCCS and ToM tasks and showed preliminary evidence of a deficit relative to typically developing children. They used a larger sample and two matched groups of typically developing children. One group was matched on chronological age and verbal mental age, and the other, was matched on chronological age and nonverbal mental age. The children with autism were impaired relative to both matched groups on the ToM and DCCS task. Although the authors do not report the chronological or verbal mental ages of their participants, they provide preliminary evidence of impairment in set shifting/rule use among children with autism.

Ozonoff et al. (2004) compared the performance of 79 participants with autism and 70 typically developing persons on two measures of EF, including the Intradimensional–Extradimensional shift (ID/ED), which requires the ability to switch flexibly between dimensions. On this task, children learn through trial and error to attend to a relevant dimension (e.g., shapes) and ignore an irrelevant dimension (e.g., lines). After the learning criterion is reached, two types of shifts are presented in standard order. In the first intradimensional shift, new shapes and lines are introduced, but the relevant dimension is not changed (children are still required to respond to the shape). In the second shift, the relevant dimension is changed, and children must now switch and respond to a previously non-rewarded dimension (e.g., the lines). Finally, in the third extradimensional reversal shift, the children must switch back to select one of the shapes. This task thus builds in a control condition that allows for comparisons of shifts within dimensions and shifts across dimensions.

The first switch in the ID/ED task does not require cognitive flexibility per se, because it measures the ability to generalize the rules from one set of stimuli to another. The second and third shifts measure cognitive flexibility because they require participants to change the dimension to which they are responding. Ozonoff et al. (2004) hypothesized that if children with autism were impaired in their ability to shift between mental sets, they would require additional trials to reach the learning criterion for the intra- and extradimensional shifts than would the typically developing comparison participants. The performance of the persons with autism was assessed in relation to the typically developing persons matched on chronological age (range 6–47 years) verbal, performance, and full-scale IQ. In comparison to typically developing persons, the individuals with autism in both the higher (mean IQ 111) and lower (mean IQ 86.7) IQ groups performed similarly on the intradimensional shifts but required more trials than the typically developing peers on the extradimensional shifts.

Evidence from studies of set shifting among persons with autism suggests a robust impairment among older groups of children as well as indications that these impairments extend from childhood. Comparisons to children with moderate intellectual disabilities on the A-not-B tasks with and without invisible displacement were not significant, but did reveal a trend towards poorer performance by the children with autism. The performance of children with autism on the DCCS was related to their performance on ToM measures, and this performance was impaired in relation to matched groups of typically developing children. On the ID/ED shift, individuals with autism were impaired in their ability to shift sets to new targets (e.g., shifting from the color game to the shape game) relative to typically developing comparison participants, but they were however, able to shift within a target category (e.g., in the shape game of the DCCS, children were able to sort by the rabbits and by the boats). Findings from the other studies using the Go/No-Go, Negative Priming, Windows and DRT tasks are consistent with evidence of impairments in cognitive flexibility. Future research is needed to clarify the developmental course of this process among persons with autism.

4. Summary

The current review of the literature attempted to examine what we know about the EF components of inhibition, working memory and set shifting among persons with autism, and to place this knowledge within the theoretical framework of developmental psychopathology. Findings from studies of a variety of EF processes utilizing different measures, comparison participants and matching measures were used to examine the development of EF among persons with autism. Results from these different studies were considered with respect to methodological choices made by researchers such as the choices of comparison participants, experimental tasks and the matching measures used to compare the performance of persons with autism to other groups of participants.

Among persons with autism, inhibition abilities appear to be intact, when inhibition is strictly defined and when participants have developmental levels greater than 6 years. In contrast, the nature of working memory impairments among persons with autism is more complex. In later childhood and adolescence, there is some evidence of impairments on measures of working memory span but not measures of interference among persons with autism. Impairments in cognitive flexibility are robust during the adolescence and adulthood of persons with autism, and the literature reviewed here supports the notion that these impairments may also be noted at younger developmental levels.

5. Conclusions

The observation that the behavior of persons with autism resembles that of persons with frontal lesions was first noted by Damasio and Maurer (1978), and tested empirically by Rumsey (1985) with the WCST. These initial formulations were central to the development of theories of executive dysfunction among persons with autism. The notion of impairments in EF among persons with autism is robust, especially with the use of the WCST and other adult measures of EF (Pennigton & Ozonoff, 1996). This evidence of increased perseveration among persons with autism relative to others is indicative of frontal lobe involvement, but intricacy of the WCST precludes definitive conclusions on the status of EF deficits in autism in at least two ways. One, the WCST is not appropriate for use with young and lower functioning populations as the task demands are high. Two, perseverative responses can be attributed to a variety of underlying processes such as inhibition, working memory and set shifting, therefore, the source of perseverative errors is difficult to isolate through this task.

Through the examination of component processes, the delineation of EF impairments can be fine tuned, but methodological differences across studies regarding the choice of tasks, comparison groups, and matching measures limit the conclusions that can be drawn. In an attempt to contribute to the understanding of EF in autism, findings from studies of inhibition, working memory, and set shifting/cognitive flexibility were considered in relation to participants developmental level, the tasks used to measure of EF, and the comparison groups chosen to compare the performance of persons with autism. Each of these layers provides unique information towards understanding the development of EF among persons with autism. In the present review of the literature on EF among persons with autism, we illustrate the importance of considering these issues in mediating the interpretation of research findings.

The examination of specific processes into their component parts allows for both a theoretical and empirical refinement of the characterization of EF processes among persons with autism throughout their lifespan. Understanding the development of EF among persons with autism in relation to developmental levels provides a framework for examining these processes at a neurological level. Findings from cognitive psychology provide information as to where and when to look for impaired processing in the brain, which would allow for an even more refined understanding of EF processes throughout the lifespan of persons with autism. This type of deconstructing process is useful, but EF must then be understood in developmental and functional terms that incorporate a holistic and agentive view of the child, their goal-directed actions and the contexts within which they act.

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